Integrating Aquaculture with Crop Systems

An Aquaponic Enterprise Project Proposal for the Ntinga Multipurpose Co-Operative in Philippi, South Africa

by

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Thesis presented in partial fulfilment of the requirements for the degree of Master of Philosophy in Sustainable Development in the Faculty of Economic and Management Sciences at Stellenbosch University

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March 2015

Declaration

By submitting this thesis electronically, I declare that the entirety of the work contained therein is my own, original work, that I am the sole author thereof (save to the extent explicitly otherwise stated), that reproduction and publication thereof by Stellenbosch University will not infringe any third party rights and that I have not previously in its entirety or in part submitted it for obtaining any qualification.

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Abstract

Stellenbosch University was approached to assist with developing a techno-financial model for an urban freshwater aquaculture system in Philippi, Cape Town. Rapidly growing urban areas are predominantly becoming concentrated zones for malnutrition and poverty which require attention. Having enough food to eat does not mean that a family is food secure, the problem is usually associated with the lack of access to nutritious food. Fish is seen as an extremely healthy food which has the potential to effectively support food security and alleviate malnutrition.

Aquaculture is identified as a largely underdeveloped sector in South Africa. It is currently undergoing rapid transition, being promoted by government as an industry that has potential to develop and create jobs, provide food security and grow the South African economy.

Aquaponics- a method to integrate aquaculture with growing crops in a symbiotic system is a highly resource efficient closed-integrated food producing technology which has the potential to benefit from South African biosecurity regulations and climate-geographic characteristics. It is viewed as an effective food production alternative to deal with the challenges of declining high quality freshwater resources and available arable land.

Training and capacity building is important for the development of aquaponic technology. This study explores and identifies the advantages aquaponic technology development would have in South Africa. The study has reviewed and assessed the fundamental principles for aquaculture production and management required for aquaponic systems development and management. A practical case study identifies the daily challenges and design parameters of aquaponic systems. The study is concluded with a techno-financial project proposal which shows how aquaponic systems can be planned

Opsomming

Universiteit Stellenbosch was genader om ‘n tegno-finansiele model to ontwikkel vir ‘n stedelike akwakultuur plaas in Philippi, Kaapstad. The tempo waarteen die stedelike areas groei ontwikkel kommerwekkende uitdagings soos wanvoeding en armoede.

In hierdie studie is vis geindentifiseer as ‘n uiters voedsame aanvulling in die dieet van Suid Afrikaners. Akwakultuur is grootliks agter in terme van ontwikkeling. Dit word beskou as ‘n sektor wat groot potensiaal inhou vir Suid Afrika se eknomiese groei, werkskepping en voedselsekuriteit.

Akwaponika is die hersirkulerende integrasie van akwakultuur en hidroponika. Akwaponika hou groot voordele in terme van Suid Afrika se biosekuriteit regulasies and geografiese eienskappe en is ‘n effektiewe manier om gebruikte akwakultuur te suiwer.

Opleiding en beplanning word gesien as ‘n fundamentele benadering tot suksesvolle akwaponika ontwikkeling. Hierdie studie bestudeer die Suid Afrikaanse omgewing en potensiaal vir akwaponika ontwikkeling. Die fundamentele beginsels van akwakultuur en hidroponika bestuur en produksie is saamgesit wat beskou word as die aanbevele manier om akwaponika te bestuur. ‘n Praktiese gevallestudie toon die daaglikse uitdagings aan en gee raad oor daaglikse bestuur van akwaponika stelsels. Die studie word afgesluit met ‘n tegno-finansiele model wat wys hoe om ‘n akwaponika sisteem te beplan.

Acknowledgements

This project proposal is the product of the work done over the past two years. I was fortunate to be under guidance of my Father, Martiens van der Merwe who have supported my studies and who is ever willing to facilitate me through the challenges faced in this project. Thank you for your motivational support!

I express my thanks to supervisors, Henk Stander of the Aquaculture Division and Gareth Haysom of the Sustainability Institute, and mentors Estelle Kempen from the Agronomy Department and Riaan Coetzer from Richmond Mining and Exploration, for their technical support and guidance.

A special thanks and love to my beautiful newly wedded wife Michélene, for enduring the tough year with me and supporting me in every way, without you this wouldn't have been possible.

Lastly I thank our Heavenly Father who has guided me in this project, who has provided me wisdom, perseverance and emotional capacity to deal with all the issues faced in this project. I dedicate this work to You.

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List of Acronyms, Abbreviations

AASA:	Aquaculture Association of Southern Africa
AIS:	Alien and Invasive Species Regulations and Associated Species Lists
FAO:	Food and Agriculture organization of the United Nations
GDP:	Gross Domestic Product
NEMBA:	National Environmental Management: Biodiversity Act, 2004 (Act 10 of 2004)
NGO:	Non-Governmental Organization
UN:	United Nations
WAF:	Welgevallen Aquaponics Facility
WEF:	Welgevallen Experimental Farm

B-BBEE	Broad-Based Black Economic Empowerment
CAPEX	Capital Expenditure
CEF:	Closed Environment Farming
DHA:	Docosahexaenoic acid
DWC:	Deep water Culture
EIA	Environmental Impact Assessment
EMP	Environmental Management Plan
EPA:	Eicosapentaenoic Acid
FCR:	Feed Conversion Ratio
H_2S:	Hydrogen sulphide is the chemical compound with the formula H_2S. It is a colourless gas with the characteristic foul odour of rotten eggs; it is heavier than air, very poisonous, corrosive, flammable, and explosive.

HDPE	High Density Polyethylene
IBC	Intermediate Bulk Container
NH_3:	A compound of nitrogen and hydrogen with the formula NH_3. It is a colourless gas with a characteristic pungent smell - Ammonia
NO_3:	A polyatomic ion with the molecular formula NO_3- Nitrates are mainly produced for use as fertilizers in agriculture because of their high solubility and biodegradability - Nitrate
OPEX	Operational Expenditure
Ppm:	Parts per million
RAS:	Recirculating aquaculture system
TDS:	Total dissolved solids
The Code:	Code of Conduct for Responsible Fisheries
TSS:	Total suspended solids

Definition of Terms/ Concepts

Aquaculture:	Aquaculture is the farming of aquatic organisms such as fish, shellfish and even plants.
Aeroponics:	A plant-cultivation technique in which the roots hang suspended in the air while nutrient solution is delivered to them in the form of a fine mist.
Amino Acid:	A simple organic compound containing both a carboxyl (—COOH) and an amino (—NH_2) group commonly referred to as the building blocks of all biological proteins.
Aquaponics:	The integration of recirculating aquaculture and hydroponic plant production.

Culture:	Maintain living organisms in conditions suitable for growth.
Fisheries:	A place where fish are reared for commercial purposes.
Fully Fished:	Describes a fish stock for which current catches and fishing pressure are close to optimum
Green Infrastructure:	Green Infrastructure is a network providing tools for solving urban and climatic challenges by building with nature.
Hydroponics:	The cultivation of plants in nutrient solutions with or without an inert medium (as soil) to provide mechanical support.
Horticulture:	The art or practice of garden cultivation and management.
Inland:	Situated in the interior of a country rather than on the coast.
Marine:	Relating to or found in the sea.
Multitrophic:	Involving species of different trophic levels of the same food chain
Nitrification:	The oxidation of reduced forms of nitrogen, ultimately to nitrate
Nutrient:	A substance that provides nourishment essential for the maintenance of life and for growth.
Omega-3 fatty acid:	Any of several polyunsaturated fatty acids found in cold-water fish, leafy green vegetables and vegetable oils. Omega-3oils have cholesterol reducing and anticoagulant properties.

Osmoregulation:	The maintenance of constant osmotic pressure in the fluids of an organism by the control of water and salt concentrations.
Overfished:	Depleted stock of fish (in a body of water) by excessive fishing.
Photosynthesis:	The process by which green plants use sunlight to synthesize nutrients from carbon dioxide and water.
Recirculating Aquaculture:	A closed-loop method to grow fish in continually recirculating water.
Tilapia:	Tilapia is a native African freshwater fish belonging to the family Cichlidae.
Trout:	Trout is the name for a number of species of freshwater fish belonging to the genera Oncorhynchus, Salmo and Salvelinus, all of the subfamily Salmoninae of the family Salmonidae.
Wild Capture Fisheries:	Fish captured in its natural habitat.

"…Population increases will soon cause our farmers to run out of land. The amount of arable land per person decreased from about an acre in 1970 to roughly half an acre in 2000 and is projected to decline to about a third of an acre by 2050, according to the United Nations. With billions more people on the way, the traditional soil-based farming model developed over the last 12,000 years will no longer be a sustainable option.

Irrigation now claims some 70 percent of the fresh water that we use. After applying this water to crops, the excess agricultural runoff, contaminated with silt, pesticides, herbicides and fertilizers, is unfit for reuse.

The developed world must find new agricultural approaches before the world's hungriest come knocking on its door for a glass of clean water and a plate of disease-free rice and beans. Imagine a farm right in the middle of a major city.

Food production would take advantage of hydroponic and aeroponic technologies. Both methods are soil-free." and use up to 90 percent less water than conventional cultivation techniques.

- Dr. Dickson Despommier- New York Times (Despommier, 2009)

Chapter 1 -Introduction

1.1 Introduction

The University of Stellenbosch's Aquaculture Division (here after referred to as the University) was tasked to assist a group of African female urban farmers in Philippi, Cape Town to develop an urban aquaculture[1] farm, and set up a basic business plan to access funding from the Department of Trade and Industry.

The site is situated on the northern edge of Philippi and Mitchells Plain, which is largely known as the Cape Flats (City of Cape Town, 2013a), which make up a low income area with widespread poverty and food insecurity (Battersby, 2011). Land in the Cape Flats and surrounding townships are fiercely contested for due to the shortage of houses and quality living standards in the informal settlements in the Cape Flats (Essop, 2014; Knoetze, 2014; Sesant, 2014). The existing urban agricultural areas in Cape Town such as the Philippi Horticultural Area (PHA) are constantly threatened by the desperate need for housing and industrial space (Haysom & Battersby-Lennard, 2012).

Malnutrition rates in South Africa's urban areas are increasing- Raising the question as to why this is a problem when South Africa is a food secure nation with a well-developed agriculture sector (McLachlan & Thorne, 2009). South Africa's aquaculture industry however remains largely underdeveloped in both regional and international terms (Rana, 2011; Department of Agriculture Forestry & Fisheries, 2013; Salie, 2014). A lot of energy and development surrounds aquaculture, freshwater aquaculture development is currently the fastest growing food producing sector in the world with Africa showing the fastest production growth (FAO, 2014).

The underdeveloped aquaculture industry poses a great growth potential to contribute towards the society of South Africa. Not only will it create jobs and add to the Gross Domestic Product (GDP), but it also poses the ability to deliver affordable high quality food (Anyila, Rana, Salie, 2005; Department of Trade and Industry, 2007).

Fish is an extremely nutritious food source having a unique nutritional composition containing many minerals and most vitamins we require for healthy bodily function and active lifestyle, fish also contains high levels of quality protein which contains well balanced amino acids (Murray & Burt, 2001; Cheung, Lam, Sarmiento, Kearney,Watson,Zeller, Pauly, 2010) . The fatty acid profile of fish contains significantly more omega-3 fatty acids in comparison to other white and

[1] The cultivation of aquatic organisms

red meats (Williams, 2007). In recent years concerns are growing to determine the quality of fish in regards to heavy metal pollution (Ling, Wu, Yang, and Hsu, 2013). Fish contamination has been linked to areas that are highly industrialized around the globe. Strict measures have to be in place to regulate, country of origin and methods of farming to deliver safe, quality fish. The best way is to develop a safe and regulated local aquaculture industry.

One of the major challenges facing the South African freshwater aquaculture industry is to gain clarity on the regulation of invasive species management. It was therefore partly the reason that commercial aquaculture development had such a slow growth as fish farmers were prohibited from using a wider variety of faster growing commercial fish species (Department of Trade and Industry, 2007).

October 1, 2014 Government promulgated an updated National Environmental Management: Biodiversity Act (NEMBA) 10 of 2004, which stated that a select invasive fish species would be permitted but regulated through permits and management guidelines (Department of Agriculture Forestry & Fisheries, 2013; Department of Environmental Affairs, 2014). This updated list allows for aquaculture farmers to use faster growing fish species such as the Nile Tilapia which are popular and well-researched across the world (El-Sayed, 2006; Rana, 2011; Salie, 2014) .

The regulation of invasive species calls for control through prevention as the most effective method to address environmental threats (Leung, Finoff,Shogen, Lewis, Lamberti, 2002). Cleaner and safer methods such as closed recirculation systems that pose a reduced risk to biosecurity and environmental harm are encouraged by government though the NEMBA (Hinrichsen, 2007).

The quote of Despommier (2009) on page xiv calls for an investigation of an alternative approach towards agriculture, arguing that the need for an alternative approach is driven by the future challenges, namely:

- Population growth pressures;
- Contested land/less arable land resources; and
- The supply of freshwater resources being used as agricultural irrigation.

He calls for new agricultural approaches such as hydroponic[2] and aeroponic[3] technologies, which pose advantages in water use efficiency and control. It can be argued that aquaponics[4] could have been added to this argument, as aquaponics is the integration of aquaculture and hydroponics.

Aquaponics is an integrated aquaculture method which produces large quantities of fish and plants with relatively small volumes of water in a recirculating symbiotic environment (Rakocy, Masser & Losordo, 2006). The symbiotic nature of aquaponics efficiently recycles waste water end products of aquaculture and uses this nutrient-rich water to diversify production by growing plants which in turn cleans the water for reuse for aquaculture. Worldwide many aquaculture farmers are reverting to alternative methods to fish farming like integrated aquaculture as a method to efficiently utilize natural resources and to diversify production of healthy food (Mathias, Charles & Baotong, 1998).

Many subsidized and government sponsored food producing projects have failed to operate sustainably due to several complex reasons. One of the main reasons are due to a lack of capacity and planning, (Stoltz, 2010; Yeld, 2013; George, 2014). For this reason research and development, and capacity-building in the field of recirculating aquaculture is seen as critical to improve understanding of it and avoid challenges that restrict the sectors' development.

The University acquired a recirculating aquaculture system (RAS) (hereby referred to as Welgevallens's Aquaponic Facility or WAF) which is based on aquaponic technology. The University decided to utilize Welgevallen's Aquaponics Facility as a case study to develop a project proposal for the Ntinga Multipurpose Co-operative. The project proposal is compiled by information and experience gathered at Welgevallen Experimental Farm. All major challenges identified at the Welgevallen Aquaponics Facility and in the relevant literature were addressed through the design of the project proposal.

The aim of this study is to gain a better understanding of the management and operation of an aquaponics system and identify challenges associated with integrated aquaculture in terms of design, inefficiency and daily management. Academic and industry-related literature was used to complement the practical project related technical research. The project-related research and

[2] Greek term for 'cultivation in water', was developed by Professor William Frederick Gericke in the early 1900's and have since changed the face of farming (Kempen, 2012).
[3] A plant-cultivation technique in which the roots hang suspended in the air while nutrient solution is delivered to them in the form of a fine mist.
[4] The integration of recirculating aquaculture and hydroponic plant production.

literature review are combined to inform an integrated aquaculture project proposal for Ntinga Multipurpose Co-operative.

This study took the form of a project proposal, which was intended to act as a guideline for development. The proposal hopes to result in a funding, knowledge generating and operational mechanism for integrated aquaculture farming for the Ntinga Multipurpose Co-operative.

While this project proposal focuses on the Ntinga Multipurpose Co-operative, the study is not restricted to a specific site. The information gathered builds South African-specific knowledge specific to integrating aquaculture with crop production, informed by a detailed scientific and technical trail. The information generated has the potential to benefit aquaculture, integrated aquaculture, hydroponic and aquaponic farmers.

The research and development of closed aquaponic systems can be thus considered a sustainable alternative approach towards addressing issues discussed above as it addresses social, environmental and economic issues and challenges of development.

1.2 Background

The Ntinga group gained a five year land lease agreement in Philippi from the City of Cape Town. The Ntinga Multipurpose Co-operative wishes to use the land for small scale agriculture purposes with an interest in incorporating aquaculture into their farming approach. The Ntinga Multipurpose Co-operative aims to access financial support in order to develop the model further and will use the multi-purpose farming model with a financial plan and technical framework to source funds.

The site designated for the project is situated in an urban environment surrounded by informal townships and residential areas, located in the same complex as the Philippi Agricultural Market which is part of the City of Cape Town's urban upliftment projects. The upliftment projects were developed to stimulate economic growth in the Philippi area.

The research was conducted at the University of Stellenbosch aquaponics facility. A private mining company donated the facility to Stellenbosch University in 2013. The purpose of the aquaponics facility is to conduct academic research testing the performance, challenges, technical innovations and opportunities associated with aquaponics and other related production approaches.

1.3 Problem Statement

As our global population growth is forecast to increase, an enormous amount of pressure will be put on our natural resources and food supplies (Battersby, 2012; MacDevette, Manders, Eickhout, Syihus, Prins, Kaltenborn, 2009). Many of the world's poorest migrate and live in urban areas in which they remain unable to escape the poverty trap (Ravallion, 2002). Attention must be given to the future of food security in urban areas and supplying a sustainable source of protein (Crush, Frayne & Mclachlan, 2011).

Despite global progress in alleviating food security, Sub-Saharan Africa remains a problem with the highest prevalence of undernourishment (FAO, IFAD & WFP, 2014). The South African urban populations are increasing rapidly with most of the poor being cut off from their means of food production and food availability (Battersby, 2012). This leads to several challenges such as stressed public services, increased food insecurity and increased poverty.

As the South African population urbanizes it systematically decouples the population from food sovereignty and traditional agrarian lifestyles. As agricultural activities are pushed further away from population centres, it leads to products being transported from greater distances. Oil shocks and energy price increases have an indirect price effect on transported commodities, especially food (Wakeford, 2006). Our cities have become unsustainably dependent on being fed from food produced outside its boundaries. Cities are increasingly dependent in food transported from distant areas across the globe. Cities are increasingly decoupled from food sources and residents are increasingly dependent on food access (Battersby, 2012).

As one of the possible food security approaches, South Africa's cities will have to find solutions to secure innovative local food production, processing, transportation and waste solutions. Most of the supermarkets are located in areas which require motorized transport (Battersby, 2012). As a strategy to enable the poor to have access to healthy food, focus should be given to strengthening local markets and farms.

Aquaculture is currently the fastest developing food producing sector in the world (FAO, 2014), and is viewed as one means to supply the ever growing global population with high quality protein.

Freshwater aquaculture is largely undeveloped in South Africa, but only in recent years has seen a surge of interest from government and private sector seeking to both invest in, and more generally, increase aquaculture development (Stafford, 2013).The main reasons behind the slow development are fourfold (Department of Trade and Industry, 2007; Rana, 2011; Salie, 2014):

- South Africa does not possess a native marketable-domesticated fish species;
- Policy which prohibited (until recently) exotic fish species to be commercially farmed (because of the possible threat to biodiversity and water pollution);
- The South African extreme climatic and geographic landscape do not allow for favourable conditions that supports aquaculture development;
- There is inadequate technical knowledge, skills and production-related technology to support the sector.

Integrated aquaculture, especially aquaponics has gained much interest amongst hobbyists and small farmers. However the majority of aquaponic projects either fail or rely on external funds for support. Many interested farmers, hobbyists and development practitioners do not possess the required knowledge on aquaculture and hydroponics management. There is thus a need for a management guideline and business model for integrated aquaculture system development and management.

The way we view waste needs to change to a way that we view it on micro level; a constant flow of nutrients that should be integrated into alternative means of production. Too much of our waste ends up “wasted” on landfill sites or as water pollution, often resulting in algae blooms destroying aquatic ecosystems. Organic waste should be viewed as a valuable resource in food production. New and innovative ways need be found to minimize waste and to symbiotically incorporate it into local food production.

Food production needs to cut down on its ecological footprint, currently one of the highest of all industries (Smith, Martino, Cai, Gwary, Janzen, Kumar, McCarl, Ogle, O'Mara, Rice, Scholes, Sirotenko, 2007; Khan, Khan, Hanira, Mu, 2009). The global rise in water scarcity is partially a consequence of an increased food demand from an growing population (Molden, Oweis, Steduto, Kijne, Hanira, Bindraban, Bouman, Cook, Erenstein, Farahani, Hachum, Hoogeveen, Mahoo, Nangia, Peden, Sikka, Silva, Turral, Upadhvava, Zwart, 2007). The current food system in South Africa (and elsewhere produces food on farms that are located far from where the food is consumed. This results in long transportation lines with energy and other associated processes required, to keep food fresh. Farmers themselves are challenged by rising energy costs with those dependent on high energy-related inputs being most heavily impacted by volatile energy prices (Wakeford, 2006).

1.4 Research Aim and Objectives

The project proposal is aimed at exploring the challenges associated with aquaponics production and management and to propose solutions to avoid these challenges. The study aims to highlight challenges facing aquaculture development in South Africa and recommend ways to overcome it with alternative options (this study focuses on the building blocks and technologies which makes up aquaponics namely aquaculture and hydroponics and discusses the challenges surrounding these technologies to better understand the technology and potential of aquaponics). The study looks at the design and operation of aquaponic systems and recommends effective and/or improved design and management techniques.

The objective is to deliver a project proposal to the Ntinga Multipurpose Co-operative and to provide small-to-medium-scale aquaponic farmers with knowledge on how to operate, design and maintain aquaponic systems.

1.5 Materials

This project proposal was drafted as a result of empirical research conducted on over six months at the WAF. The project proposal was done on request of Ntinga Multipurpose Co-Operative and serves as a techno-financial plan for developing their project.

The project proposal is in accordance of one of the options allowed by the MPhil in Sustainable Development degree. The thesis thus does not take the form of a conventional academic thesis but rather as a case study and project proposal.

The case study experiment that has been carried out at the WAF consisted of 3 separate +- 10 000L recirculating aquaculture systems. Each of these systems contains:

- 2 x Aquaculture tanks;
- 1 x Waste separator and solids settler tank;
- 1 x Flatbed biofilter;
- 1 x Grow bed
- 1 x Sump tank

- 1 x pump

The other materials used in the system were:

- 4 x small air compressors
- Aeration pipes
- 1 x Heat pump
- 1 x Pool pump
- 1 x 1000L IBC tank
- HDPE pipes for heat exchange in the heat exchange system

See figure 1.1 for a more detailed description of the system. Please note the greenhouse tunnel is a covered area, the view in figure 1.1 just portrays the inner components.

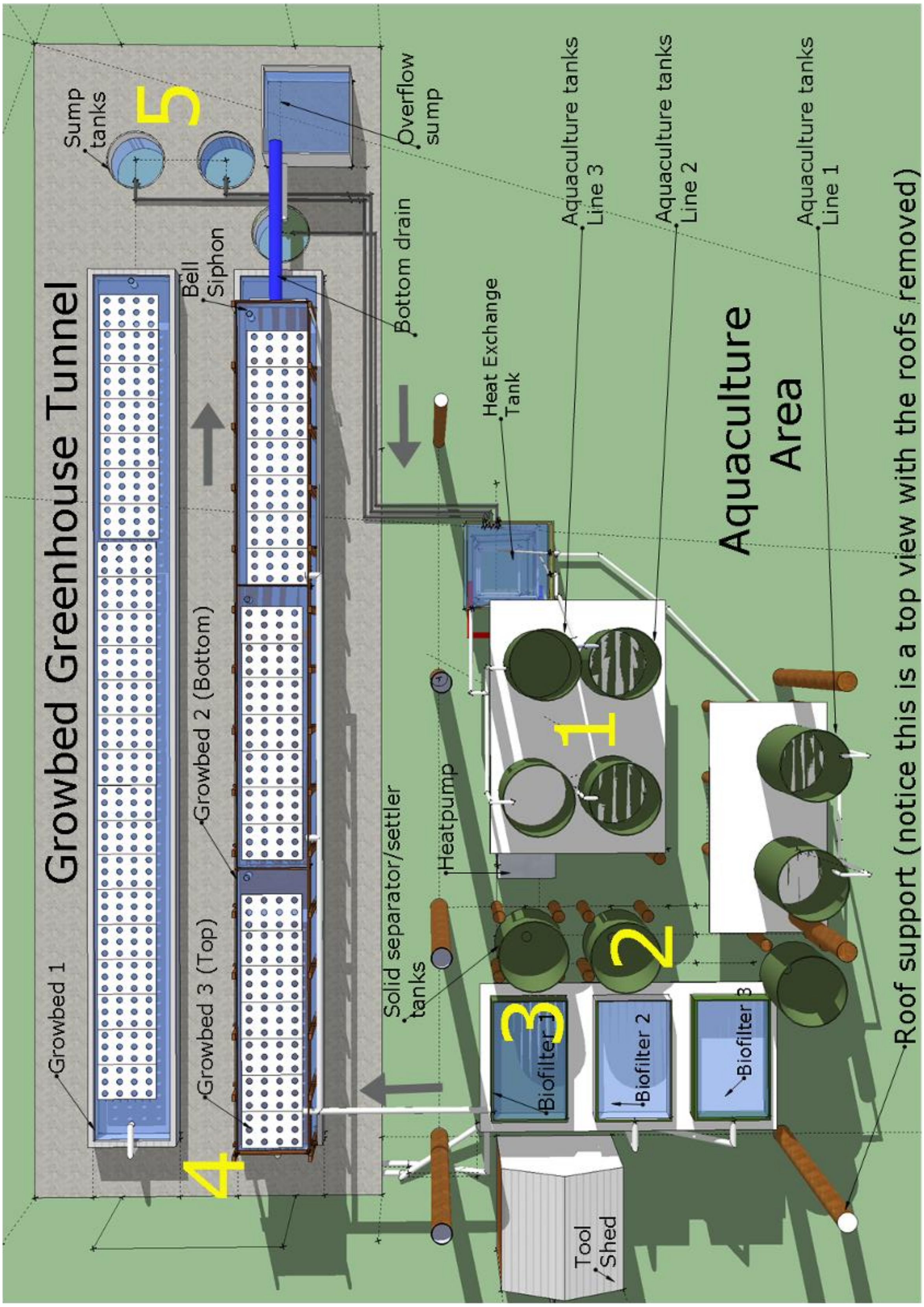

Figure 1.1: Welgevallen Aquaponics Facility list of components and water flowing by gravity from point 1-5.

Mozambique Tilapia, (Oreochromis Mossambiccus) were procured and used in the system and were fed a balanced diet of a reputable local feed producer. The plants tested were procured from a local nursery. These plants were: Course lettuce, green oak lettuce, cherry tomato, basil, chives, beetroot, Nevada lettuce, bijou lettuce, red mustard, Swiss chard and bright light spinach.

No nutrients, fertilisers or additives were added to the system. Aeration to the fish tanks and grow bed raft system were provided by compressor and wind swirl aerators.

Empirical tests were conducted over six months to observe the dynamics of fish and plants in a closed integrated system. Particular focus was given to the physical daily management duties, troubleshooting and challenges faced in the operation of small to medium scale recirculating aquaculture systems.

Part of fulfilment of the MPhil in Sustainable Development degree is to complete prescribed modules for credits. I have completed the following modules for credits at the Sustainability Institute:

- Biodiversity and Sustainable Agriculture;
- Ecological Design for Community Building;
- Wind and Hydro Energy.

The Sustainability Institute modules assisted me to gain knowledge on the challenges and opportunities faced in modern agriculture and biodiversity conservation, it assisted to my approach in this thesis to farm with nature rather than against it and to integrate waste cycles and means of production. The modules have inspired me to conduct further research into aquaponic greenhouse design, - a subject which is not discussed in this thesis.

I argue that to approach aquaponics successfully, one has to apply correct production and management practices for aquaculture and hydroponics. Thus to learn more and to understand the fundamental aspects of aquaculture and to acquire credits for the MPhil degree I enrolled for the year certificate course in aquaculture production and management hosted by the Aquaculture Division of the Department of Animal Sciences of Stellenbosch University which covered:

- Applied Biology of Aquaculture Species;
- Nutrition and Feeding of Aquaculture Species;
- Water Ecology Monitoring and Management;

- Production Systems: Design and Management
- Fish Disease and Fish Health Management
- Processing and Product Development

The certificate course in Aquaculture will be completed in mid-November 2014 when the final exams will be written.

Furthermore I enrolled and passed a non-compulsory course module; Agronomy 312 a third year semester module from the Agri-Sciences Department of Stellenbosch University on Greenhouse Production Techniques. This allowed me to learn and understand the fundamental aspects of hydroponic farming and greenhouse management which I used in this thesis and argue that understanding it is crucial to approach aquaponics:

- Controlled climate farming;
- Plant Nutrition and nutrient solution management;
- Sanitation,
- Growing systems and greenhouse management.

I also attended the 11th biennial Aquaculture Association of Southern Africa's (AASA) conference that was hosted by the University of Stellenbosch. At the AASA conference I was introduced to many facets of the industry and had the opportunity to meet the world renowned "Father of Aquaponics" James Rakocy and Dr Wilson Lennard, who share many decades of research in aquaponics and recirculating aquaculture.

Furthermore I had the opportunity to host a work session on the aquaponics and the future of agriculture at the Agri Mega Youth Conference that was hosted on the 9th of April at Bien Donné Simondium. I managed to discuss some of the basic trial and errors running WAF and shared my personal enthusiasm for opportunities in alternative agriculture. The students were fascinated by seeing and interacting with a small aquaponics model and presentation on how it worked.

1.6 Methodology

The methodology includes a study of the literature which is discussed throughout the thesis especially in the literature review (chapter 2). The deep immersive learning process was the WAF site under the guidance of my supervisor Mr. Henk Stander which I was part of planning, building, and solely responsible for start-up, management, and maintenance.

The technical inputs were gained through coursework and further literature research of the Aquaculture certificate and agronomy model taken. This supported and resulted in the development of a project proposal which makes up the thesis.

Before the business plan was fully developed a preliminary consultation with the members of the Ntinga Multipurpose Co-operative was organized to gain perspective of their needs and approach to the project. It was decided that the proposal's business plan should be set up according to the Department of Trade and Industry's guidelines which will be used to access grant funding for the project.

1.7 Motivation for the Study

Food security is defined by the prevailing definition agreed upon at the 1996 World Food Summit as "when all people, at all times, have physical, social and economic access to sufficient safe and nutritious food that meets their needs and food preferences for an active and healthy lifestyle" (Barrett, 2010). The three pillars of food security is conceptualized as being: availability, access and utilization (Barrett, 2010). Aquaponics is based on producing both fish and crops which thus provides a supply of high quality protein, fats, vitamins and minerals required for a balanced diet.

The proposed site for the Ntinga project in eastern Philippi region makes up one of the areas which are the most food insecure and where poverty is widespread. The area designated for the site make up one of the few open spaces in the City of Cape Town which is the second largest urban area in South Africa (Battersby, 2011). The city is faced by a dual challenge as stated by Haysom & Battersby (2012); "…of seeking ways to manage and administer a large portion of land, land carrying rural status, but within the immediate urban environment, located within an area of significant poverty and need, namely the Cape Flats". The Cape Flats region is an area which open land is fiercely contested by citizens, activists and pressure groups to supply housing to those living in informal settlements (SABC, 2012; Knoetze, 2014; Sesant, 2014).

The issue surrounding high quality water supply directly challenges the viability of horticultural practices in available urban land (Haysom & Battersby-Lennard, 2012). The same can be said about aquaculture practices: "The water environment [therefore] plays an integral part in the efficiency, productivity and profit margin of the aquaculture project"(Salie, 2011).

The unique situation creates a challenge to develop new ways to produce highly efficient affordable, accessible high quality food while conserving land and water quality.

During the year of 2013 I was part a team developing an aquaculture project on a farm in Mpumalanga. The main challenge identified was to reduce the impact that aquaculture has on the environment, specifically in terms of the protection of biodiversity and waste treatment. These challenges led me to researching integrated aquaculture which I identified as posing many solutions to the challenges encountered at the Mpumalanga site. The company that I worked for; Richmond Mining and Exploration decided to build and donate an aquaponics facility to the University of Stellenbosch's Aquaculture Division which enabled the research process

Research commenced in January 2014. As part of my initial research I visited several aquaponic and hydroponic projects;

- The aquaponic garden in the V&A waterfront operated by Mojo restaurant;
- Commercial aquaponic farm in Grabouw operated by a private farmer;
- Green drop aquaponic farms operated by a private urban farmer;
- An aquaponic NGO start up farm in Kuilsrivier with the goal to self-sustain its homeless shelter centre with food and profit from the farm;
- Sustainable Aquaponics NGO who aims to produce food for schools and community projects;
- Aquaponic farm in Middelburg (Mpumalanga) operated by private researcher and farmer Mike Blinkinsop;
- The R7 million Beaufort West Hydroponics Project which employed 60 people at its peak and operated between 2003 and 2007. It was managed by the Council of Scientific Industrial Research (CSIR) in partnership with the Beaufort West Municipality. The project collapsed in 2010 after it could not cover the high transport costs to deliver its produce in Cape Town.

I also did an extensive internet search for similar projects internationally and followed their project development progress, these farms include:

- The large commercial aquaponic farm operated by Paul van der Werf from Earthan Group Pty Ltd in Sharjah, United Arab Emirates;

- Aqua Vita farms operated by a private businessman Mark Doherty in Whitesboro, New York;
- Lufa farms who operates a large commercial urban rooftop hydroponics greenhouse in Montreal, Canada.
- Tropenhaus Wolhusen aquaponic greenhouse growing tropical plants in Wolhusen, Switzerland.

I noted through conversations, and eyewitness accounts that many projects were failing or are dependent on financial rescue or other external funds. Also noted were that the majority of issues are related to problems associated with a lack of knowledge on designing and managing aquaponics systems, as well as a lack of proper planning and project management.

It proved that even large government funded commercial projects such as the Beaufort West Hydroponic company which proved to be a state of the art project managed by professionals and scientists can be ruined through factors such as miscalculated overhead costs and increasing energy prices (Yeld, 2013).

These factors informed my research hypothesis and led me to researching aquaculture and hydroponic production and management techniques so as to gather first-hand experience in the management of an aquaponics facility. A further question was to analyse various different aquaponic systems and to assess the outcomes of the system design options. Concepts of different system designs were tested through basic management and testing. Hence the final design was a product which evolved through the process of empirical learning.

Late July 2014 my supervisor Mr. Henk Stander was approached by a group of African women farmers who wished to start an aquaculture project in Philippi, Cape Town. They had no knowledge of aquaculture production and management and the site proposed for the project posed several challenges. Informed by the practical research that had been carried out since January 2014, I proposed developing a business plan and project proposal directed at this project as a case study for my thesis.

Researchers on aquaponics claim that the technology allows waste water to be recirculated for secondary production of plants and that the economics of aquaponics varies from site conditions and markets (Rakocy, Masser, Losordo, 2006).This needed to be explored and tested as a practical case study in local conditions such as in the Western Cape.

The introduction, part 1.1 of this thesis, adds to the motivation and argument why the research on aquaponics has to be done and why it can be viewed as an alternative and sustainable approach to addressing the shortcoming of the South African aquaculture industry.

The current unique situation identified in South Africa's heavily undeveloped freshwater aquaculture industry can be argued to be an ideal opportunity for sustainable aquaculture development. The factors supporting an alternative approach (such as recirculating/aquaponic systems) towards aquaculture development is:

- The undeveloped aquaculture industry poses a potential to deliver more jobs, food and increase our GDP;
- Fish is highly nutritious, supporting the food security agenda;
- Closed aquaponic systems produce a high amount of fish with low volumes of water which means aquaponic systems can be operated in areas not suited for traditional aquaculture like pond or river flow through systems;
- Inappropriate climate for traditional pond or flow through river aquaculture promotes controlled recirculating systems;
- New amendment to the NEMBA act which permits under regulation faster growing fish species which promotes the economic viability of aquaculture and aquaponic operations;
- NEMBA regulation which requires strict biosecurity and control on farms farming with alien species, and promotes the use of closed integrated recirculating systems;
- Aquaponics produce both fish and crops;
- The symbiotic nature of aquaponics integrates and recycles waste water efficiently;
- Aquaponics is compact and require very little land to produce a high volume of food, supporting the fact that urban areas have very little arable and available land.

Because aquaculture requires a high level scientific approach and management expertise (Stafford, 2013) it calls for research and capacity building to support sustainable development of the aquaculture in South Africa.

1.8 Chapter Outline

This study follows the order indicated in figure 1.2. It will start with chapter 1 which introduce the background of the study and discuss the problem statement, methodology and the rationale for the study.

Chapter 2 contains the review of the literature and discuss the state of food security and urban pressures faced in South Africa. It discusses the state of international, African and South African aquaculture followed by the benefits and characteristics of fish as food source in South Africa. The latest regulatory development in South African aquaculture and what benefits and draw backs it holds for fish farmers are discussed. This is then followed by a review of alternative agriculture and sustainable aquaculture.

Chapter 3 discusses the fundamentals of aquaculture and hydroponics as an approach required for capacity building and integrating the two facets into aquaponics. This forms as a guideline to aquaponic production and management, and methods to improve systems is proposed.

Chapter 4 is a detailed description of the WAF case study, learning and development process.

Chapter 5 provides be the Ntinga Multipurpose Co-operative project proposal that includes a technical and financial plan for an aquaponic farm.

Chapter 6 concludes the entire thesis and draw together the arguments.

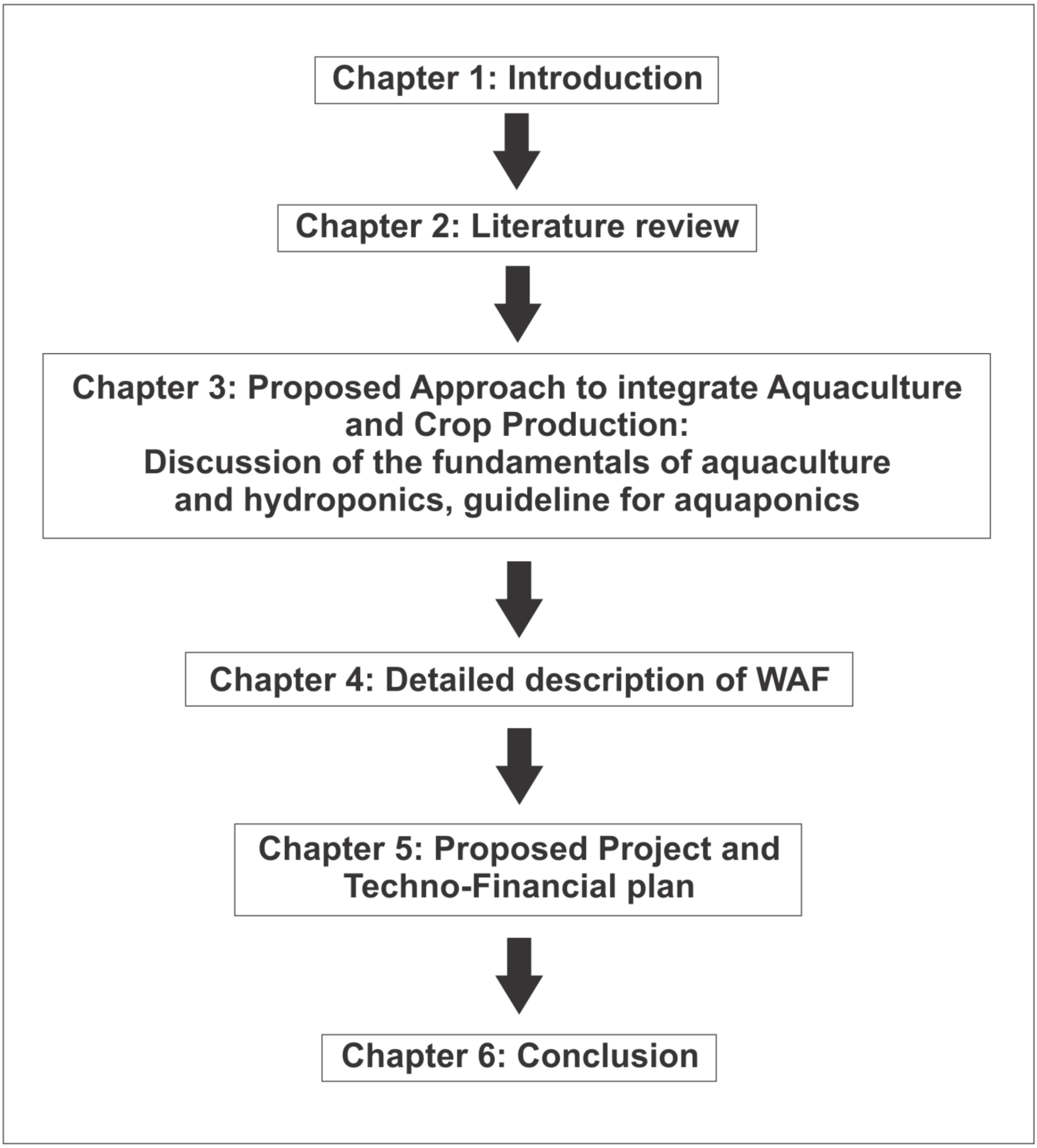

Figure 1.2: Chapter layout of thesis.

Chapter 2 - Literature Review

2.1 Introduction

Urbanization is one of the most significant phenomena our world currently faces. While many who move to the cities are in search of a brighter future, this is not always the case as poverty and malnutrition are increasing rapidly in urban areas. The demand for protein and nutritious foods remains a prominent challenge as many suffer chronic malnutrition.

In this literature review, the focus was to highlight the challenge of food security in urban South Africa with a specific view on how aquaculture can be utilized to contribute sustainably to the challenge. The current status of global and local aquaculture is important to understand the potential and approach required for sustainable development of aquaculture in South Africa it has been discussed in this study.

Alternative aquaculture methods was be discussed and argued as to why it is necessary approach and how it can be integrated into other sectors of food production. Pitfalls to development and management of aquaculture projects were discussed and an argument as to how to approach it was made.

2.2. Urban Pressure

2.2.1 Urbanization and population increase

According to UN estimates, the world's rural-urban population balance shifted in 2007 when, for the first time in history, the population of urban areas were more than that of rural areas (International Monetary Fund, 2007). It is predicted that Africa will become a predominantly urbanized population above 60%, to over 1 billion by 2050 (Goldstone, 2010; UN-Habitat, 2012).

Global population growth is forecasted to increase by 3 billion by 2050 (Brown, 2011). Feeding this future population of 9.2 billion people might be the biggest challenge we as a human race ever face.

According to 2011 statistics, 62% South Africa's population live in urban areas (Central Intelligence Agency, 2014), which is expected to reach 80% by 2050 (Todes, Kok, Wentzel, Van

Zyl, Cross, 2010). Meeting the food security of South African citizens will therefore be an increasingly urban challenge and responsibility. Rising urban poverty is associated with many of the newly urbanizing populations that are cut off from their means of subsistence food production, which they relied on for food production in rural areas (Ziervogel & Frayne, 2011).

2.2.2 Food security

According to the World Food Summit of 1996 (FAO, 2008a; Frayne, Battersby-Lennard, Fincham, Haysom, 2009; Barrett, 2010): “Food security exists when all people, at all times, have physical and economical access to sufficient safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life.” Ziervogel and Frayne (2011), suggest that the term ‘sustainable food production’ is missing from the definition set by the World Food Summit. It was however placed in the International Policy Research Institute’s (IFPRI) 2020 Vision statement, referring to food security as “a world where every person has access to sufficient food to sustain a healthy and productive life, where malnutrition is absent, and where food originates from efficient, effective, and low-cost food systems that are compatible with sustainable use of natural resources”.

According to the FAO (2014) 14% of the world’s population is undernourished, accounting for a third of all infant mortalities. According to Hasan (2012) between 2011-2013 about 842 million people suffered from chronic malnutrition. Despite an increased food production the undernourished population has increased by 9% to 12% globally since 1990 (see figure 2.1) (Barrett, 2010).

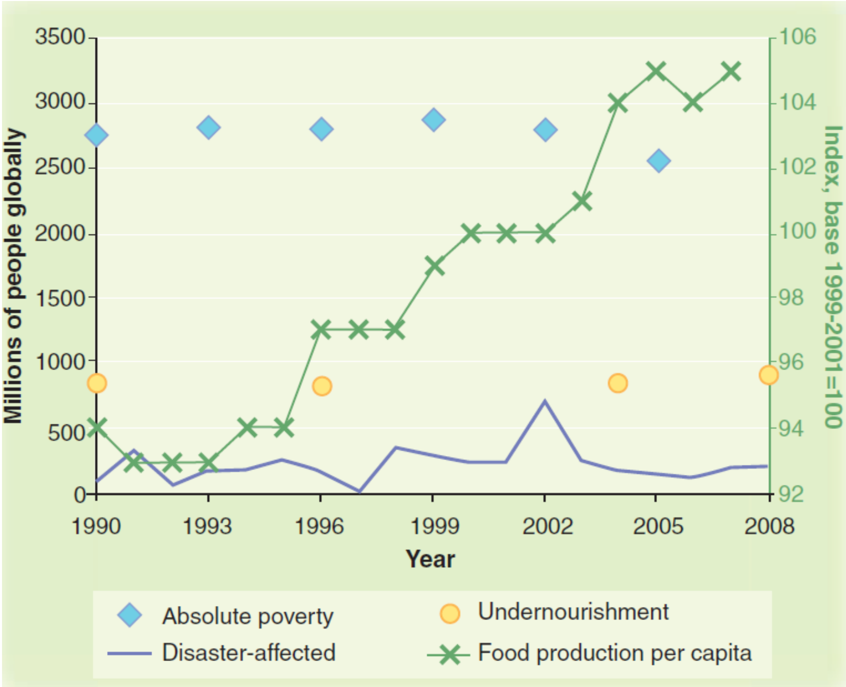

Figure 2.1: Different food security proxy indicators: It shows that although food productions have increased the undernourished population remains fairly unaffected (Barrett, 2010).

Food security is when food is available, accessible, and usable which is referred to as the three pillars of food security (Barrett, 2010). According to the FAO (2014) food supplies in the past twenty years have outpaced population growth which supported the challenge of food accessibility. Despite many citizens having access to food, many communities have access to food of sufficient calories but not sufficient nutritional value. Many South Africans suffer from malnutrition due to poor dietary diversity, and food insecurity has directly been correlated to an array of chronic illnesses, lack of energy and inability to work productively (Frayne et al., 2009; FAO, IFAD & WFP, 2014). According to Barrett (2010) it is estimated that more than a billion people lack sufficient dietary energy availability and more than two billion suffer from micronutrient[5] (mineral and vitamin) deficiencies which is called the 'hidden hunger'(FAO, IFAD & WFP, 2014). This calls for action to provide access to more nutritiously balanced food.

Battersby (2011) argues that meeting national food security will be and increasing urban challenge. The FAO (2008b), states that a major challenge for urban food security will be to provide "adequate quantities of nutritious and affordable food for urban inhabitants, with less water, land and labour". This calls for an integrated approach to food security in which systems and resources work together efficiently.

[5] A chemical element or substance required in trace amounts for the normal growth and development of living organisms.

According to Frayne et al. (2009), elements of an integrated food security strategy in a modern democratic city would consists of a food sector that is based on:

- A reduction of fossil fuel inputs;
- Maintaining and developing terrestrial and marine resources;
- Positive urbanisation;
- Improved livelihoods;
- Robust local food systems;
- Investment and development of local markets; and
- Mitigation of climate change.

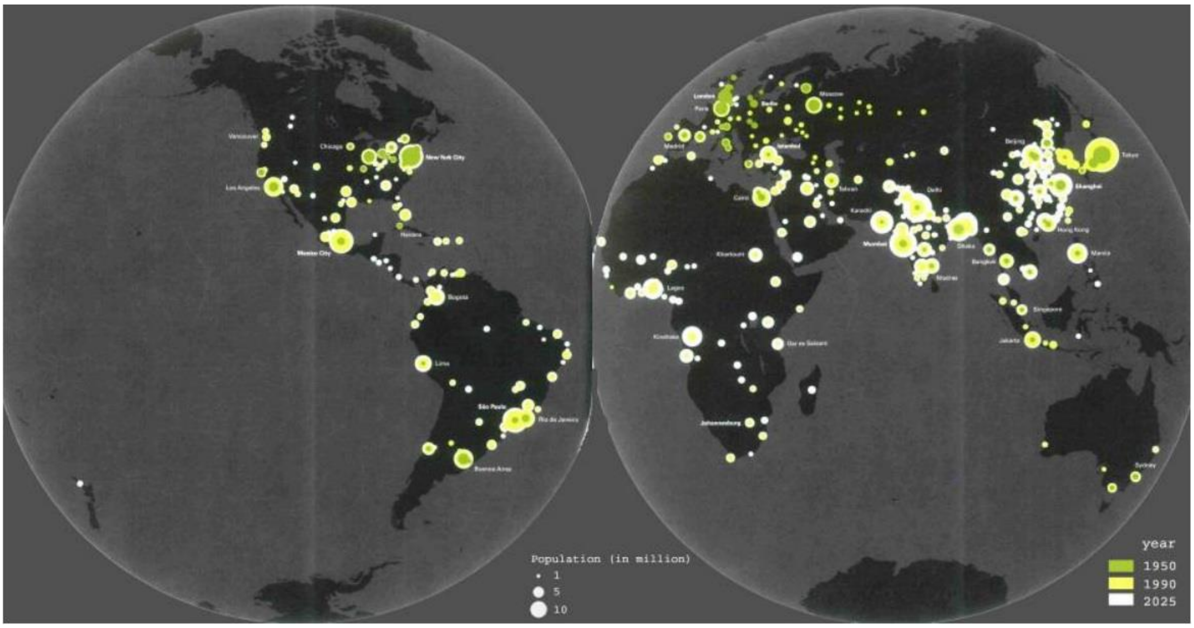

Figure 2.2: Where are cities growing (UN-Habitat, 2012)**.**

Recently, food markets have become increasingly flexible under structural changes from growing incomes, globalization, trade liberalization, lifestyle choice and new markets. Improved retail chains and supermarkets have made an impact on the distribution and consumption patterns of food not previously accessible for consumers. These changes fall under the wider term of the “big food transition” (Igumbor, Sandes, Puoane, Solekile, Schwarz, Purdy, Swart, Durao, Hawkes, 2012) and the “nutrition transition” (Popkin, 2002). These changes are not necessarily positive. Urban food can often be more expensive and other associated costs mean that newly urbanised poorer populations experience changing spending-patterns in which they tend to devote a higher amount of their income to food than what they were used to (FAO, 2014).

Cape Town is identified as one of the major urban growth points in the world (see figure 2.2 above). The City of Cape Town is South Africa's second largest urban area with a population of approximately 4 million people. Cape Town faces increasing pressures and development challenges with regards to the rising poverty, housing shortage, and urban sprawl (Battersby, 2011).

McLachlan & Thorne (2009) states that malnutrition rates in urban areas are increasing, which shows a problematic link to the urban access to food because South Africa is considered to be nationally food secure with a well-developed agricultural sector. This issue thus calls for more effective methods to make high quality food available, accessible, usable through alternative supplementation to the food supply such as aquaculture which is a very undeveloped sector in the country and has large potential to expand (Department of Trade and Industry, 2007; Rana, 2011).

2.3 Potential of Aquaculture

2.3.1 Why Aquaculture?

Fish protein represent a necessary nutritional component for many populated places on earth which have a comparative low protein intake, the potential of fish as quality food source of choice is realized and utilized worldwide and is increasing rapidly at an average of 9.9kg per capita in the 1960's to 18.9kg per capita in the year 2010 (FAO, 2014) (see figure 2.3).

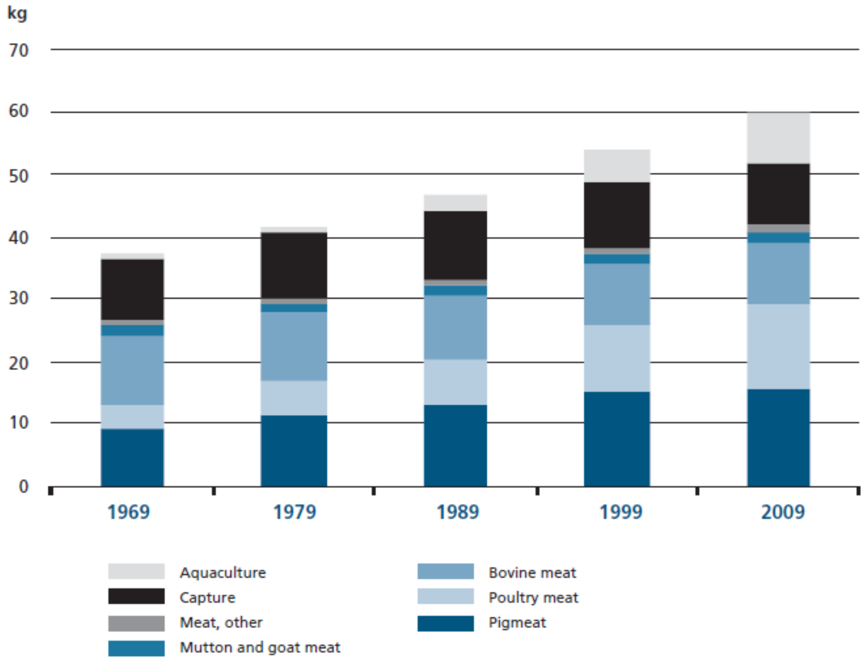

Figure 2.3: World per capita meat and fish food supply (FAO, 2014)

Linking to the definition of food security as stated in the above mentioned section 2.2.2., the focus is placed on the access to nutritious food for a healthy balanced lifestyle. Therefore to meet the challenge more attention and priority should be given to farms that produce healthy products with a diversity of quality micro and macro[6] nutrients.

According to Mathias, Charles and Baotong, (1998) aquaculture production and fisheries play an important role in providing global food security by providing communities with a source of quality protein and valuable nutrients needed for a healthy diet. A fish portion of 150g is enough to provide 50-60% of the required protein for an adult person (FAO, 2014).

Fish is low in saturated fats, cholesterol, and carbohydrates and high in a concentrated source of quality protein which is made up of well-balanced amino acids, micronutrients, and less-well known nutrients such as taurine and choline, even small quantities have proven to have a significant nutritional impact (Murray & Burt, 2001; FAO, 2014). The fatty acids in fish contains large amounts of omega-3 which is significantly more in comparison to other white and red meats (Williams, 2007).

[6] A type of food (e.g. fat, protein, carbohydrate) required in large amounts in the diet.

2.3.2 Marine or Freshwater fish?

It is recommended that consumers include a variety of different (farmed and wild caught, marine and freshwater) fish species in their diets (Usydus, Szlinder-Richert, Adamczyk, Szatkowska, 2011). Wild caught fish have a common perception to be superior in nutrition in comparison to freshwater farmed fish, a study by Szlinder-Richert, Usydus, Malesa-Ciecwierz, Polak-Juszxzak, and Ruczynska (2011) found that protein- amino acids in popular wild caught marine fish (Salmon, Cod Herring) resembles that of freshwater farmed fish (Trout, Carp, Tilapia, Catfish). Farmed fisheries have an advantage that the nutrient composition of food is kept constant and well balanced, fish are managed in a monitored environment to maintain optimum health and growth levels required by consumers (De Wet, 2011; Salie, 2014). Maintaining healthy brain and heart function (especially for patients suffering with cardiovascular diseases) it is recommended to eat fatty cold water fish species such as salmon, herring and farmed trout which is high in EPA and DHA (omega 3 fatty acids) concentrations.

Not only is wild capture fisheries under heavy threat due to exploitation and overfishing (FAO, 2010), wild capture fisheries tend to be increasingly exposed to external contaminants such as mercury, and other heavy metals (Szlinder-Richert et al., 2011; Usydus et al., 2011; Leung, Leung, Wang, Ma, Liang, Ho, Cheung, Tohidi, Yunf, 2014). Studies done by Velusamy, Satheesh, Ram and Chinnadurai, (2014) and Leung et al. (2014) showed that heavy metal contamination is not only related to marine fish as significant amounts of heavy metal concentrations and pollutants were found in both marine and freshwater fish species surrounding industrialized and developed areas. A report by Ling et al., (2013) showed that the dangers of traditional open earthen pond farming is that the contamination of fish is linked to pond sediments which means that polluted underground water, anthropogenic land use activities and air pollution have an effect on fish contamination of these farming methods.

This calls for strict control measures which monitor the quality, country of origin, feed and proper farming practices of fish. A possible solution to the issue would be the use of closed control systems such as closed recirculation systems which don’t have contact with soil sediment and can be precisely managed and regulated.

2.3.3 Global Aquaculture Development

Aquaculture is the world’s fastest growing agro-food sector, growing at an annual rate of 8.8% over the past 30 years (Toufique & Belton, 2014). With the growing benefits in quality, efficiency, technology, and knowledge, farmers are developing freshwater aquaculture farms. While global wild capture fishing remains under threat to overexploitation especially in certain regions where catches are concentrated its production levels remained fairly stable in recent years, the global aquaculture contribution have increased from about 13% to 42% (see figure 2.4 and 2.5) (FAO, 2014). The rise in global aquaculture production (see figure 2.4 and 2.6) will hopefully visibly bring down the wild capture production to safer more sustainable levels.

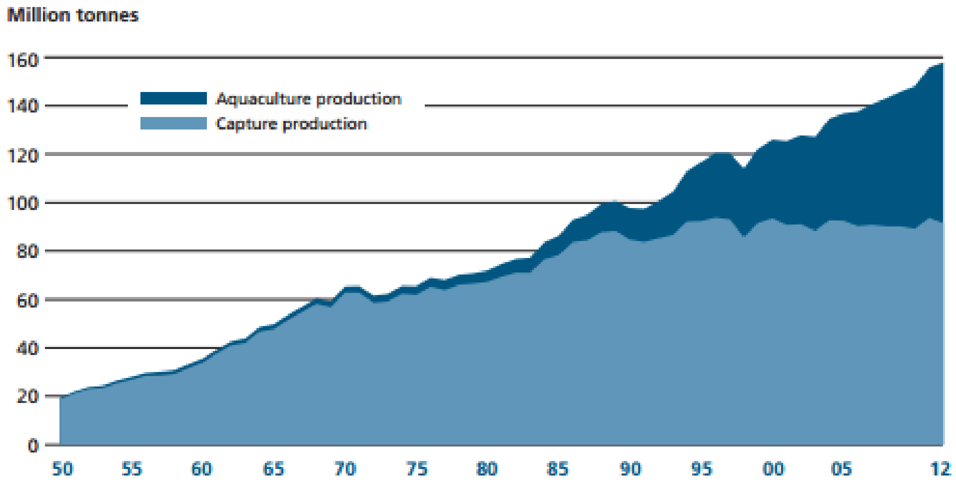

Figure 2.4: World wild capture and aquaculture/fisheries production (FAO, 2014:3)

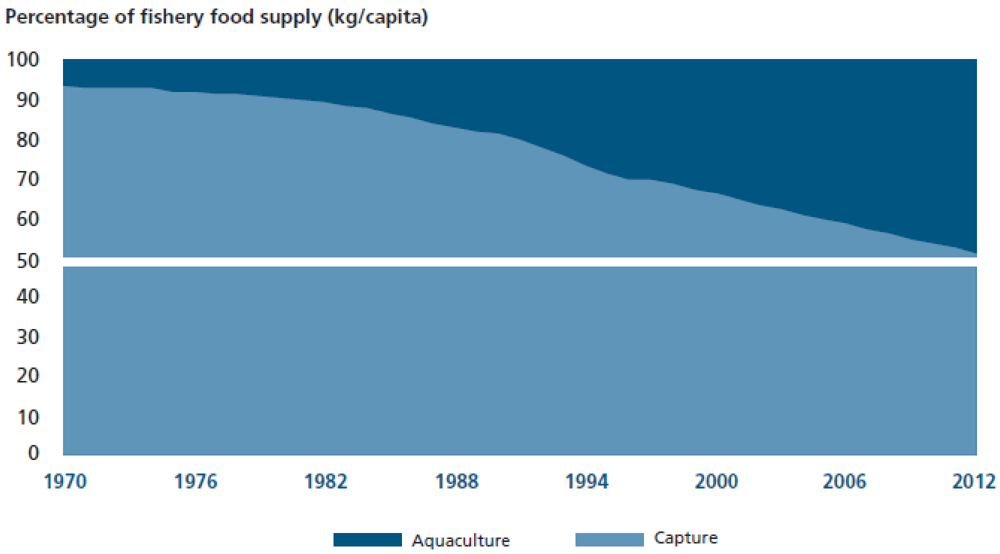

Figure 2.5: Relative contribution of aquaculture and wild capture fisheries to food fish consumption (FAO, 2014)

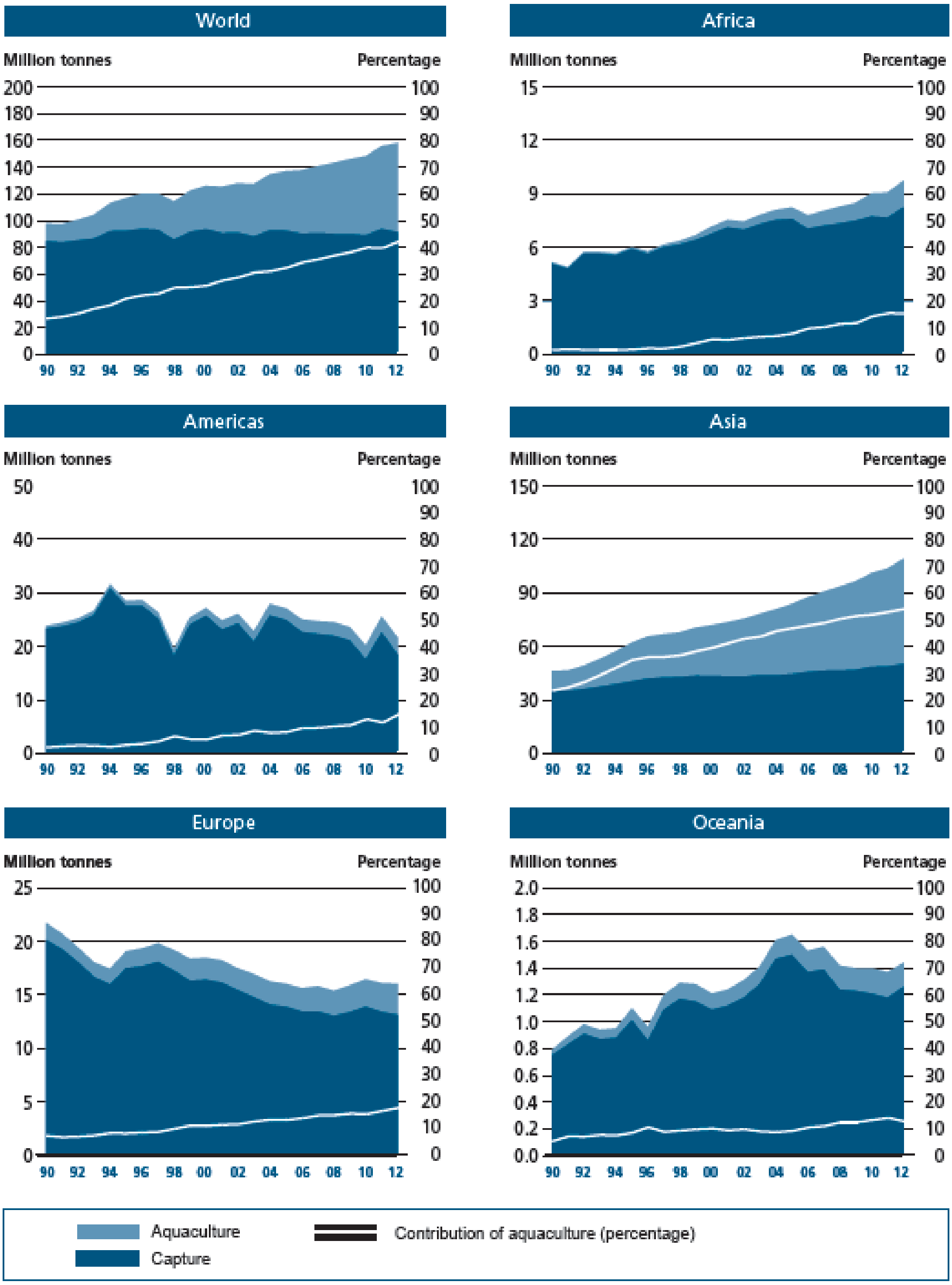

Figure 2.6: Share of aquaculture in total fish production (FAO, 2014)**.**

According to the (FAO, 2012a) the increase in fish consumption is largely driven by population growth, urbanization, change in food preference, rising income levels and efficiency in the aquaculture industry. About 58.3 million people were directly involved in the global aquaculture industry (FAO, 2014).

The international aquaculture statistics of the FAO (2014) states that America (mainly South America) and especially Africa has much lower per capita fish consumption levels and supply per capita than the global average (see figure 2.7). Africa and South America therefore have much more potential to increase its production and per capita consumption of fish, in regards to Africa this will enable to potentially close food and nutrition gaps in many regions as well as contributing to the socio economic development.

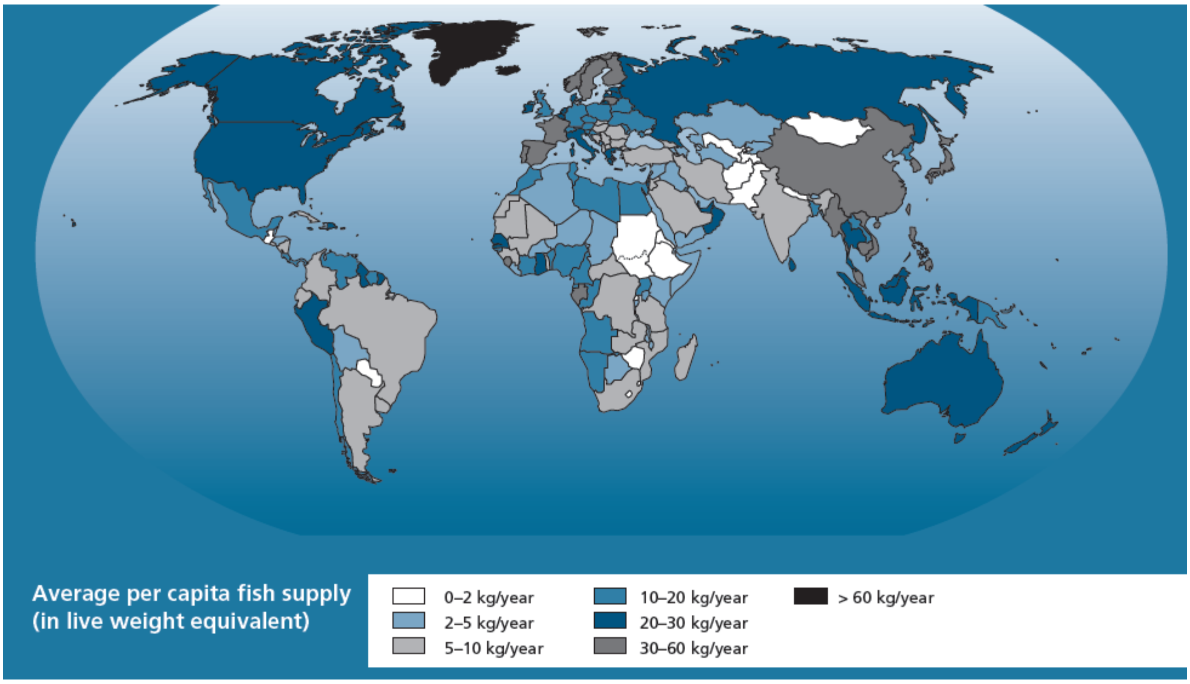

Figure 2.7: Fish food supply per capita 2008-2010 (FAO, 2014)

WORLD *(Million tonnes in live weight equivalent)*	
Total fishery production	**153.940**
Aquaculture	62.924
Capture	91.016
Fishmeal production (*product weight*)	6.103
Fish oil production (*product weight*)	0.980
Fish trade for human consumption	36.994
Fish supply for human consumption	131.741
Per capita apparent fish consumption (*kg*)	18.9
AFRICA	
Total fishery production	**9.037**
Aquaculture	1.379
Fish exports for human consumption	1.874
Fish imports for human consumption	3.876
Per capita apparent fish consumption (*kg*)	10.0
AMERICA	
Total fishery production	**22.275**
Aquaculture	2.911
Fish exports for human consumption	6.598
Fish imports for human consumption	7.657
Per capita apparent fish consumption (*kg*)	14.9
ASIA	
Total fishery production	**104.935**
Aquaculture	55.822
Fish exports for human consumption	19.241
Fish imports for human consumption	14.572
Per capita apparent fish consumption (*kg*)	21.7
EUROPE	
Total fishery production	**16.064**
Aquaculture	2.618
Fish exports for human consumption	8.264
Fish imports for human consumption	10.260
Per capita apparent fish consumption (*kg*)	21.2
OCEANIA	
Total fishery production	**1.381**
Aquaculture	0.190
Fish exports for human consumption	0.843
Fish imports for human consumption	0.652
Per capita apparent fish consumption (*kg*)	26.5

Table 2.1: Global fishery production and consumption trends per region (FAO, 2014)

African aquaculture development has seen the greatest growth per continent at 11.7% in the past 12 years (FAO, 2014). Despite the wealth of natural and human resources, Africa's contribution to global farmed fish production is very low, at 2.23% of global production (See table 2.2) (FAO, 2014) with North Africa making up 69% of the total African production. Egypt is the leading producer in Africa, producing 630 000 tonnes in 2007 (Rana, 2011).

Selected groups and countries		1990	1995	2000	2005	2010	2012
Africa	**(tonnes)**	**81 015**	**110 292**	**399 688**	**646 182**	**1 286 591**	**1 485 367**
	(percentage)	***0.62***	***0.45***	***1.23***	***1.46***	***2.18***	***2.23***
North Africa	(tonnes)	63 831	75 316	343 986	545 217	928 530	1 030 675
	(percentage)	*0.49*	*0.31*	*1.06*	*1.23*	*1.57*	*1.55*
Sub-Saharan Africa	(tonnes)	17 184	34 976	55 702	100 965	358 062	454 691
	(percentage)	*0.13*	*0.14*	*0.17*	*0.23*	*0.61*	*0.68*
Americas	**(tonnes)**	**548 479**	**919 571**	**1 423 433**	**2 176 740**	**2 581 089**	**3 187 319**
	(percentage)	***4.19***	***3.77***	***4.39***	***4.91***	***4.37***	***4.78***
Caribbean	(tonnes)	12 169	28 260	39 704	29 790	37 301	28 736
	(percentage)	*0.09*	*0.12*	*0.12*	*0.07*	*0.06*	*0.04*
Latin America	(tonnes)	179 367	412 650	799 234	1 478 443	1 885 965	2 565 107
	(percentage)	*1.37*	*1.69*	*2.47*	*3.34*	*3.19*	*3.85*
North America	(tonnes)	356 943	478 661	584 495	668 507	657 823	593 476
	(percentage)	*2.73*	*1.96*	*1.80*	*1.51*	*1.11*	*0.89*
Asia	**(tonnes)**	**10 801 531**	**21 677 062**	**28 420 611**	**39 185 417**	**52 436 025**	**58 895 736**
	(percentage)	***82.61***	***88.90***	***87.67***	***88.46***	***88.82***	***88.39***
China	(tonnes)	6 482 402	15 855 653	21 522 095	28 120 690	36 734 215	41 108 306
	(percentage)	*49.58*	*65.03*	*66.39*	*63.48*	*62.22*	*61.69*
Central and Western Asia	(tonnes)	72 164	65 602	122 828	190 654	259 781	311 133
	(percentage)	*0.55*	*0.27*	*0.38*	*0.43*	*0.44*	*0.47*
Southern and Eastern Asia (excluding China)	(tonnes)	4 246 965	5 755 807	6 775 688	10 874 073	15 442 028	17 476 296
	(percentage)	*32.48*	*23.61*	*20.90*	*24.55*	*26.16*	*26.23*
Europe	**(tonnes)**	**1 601 649**	**1 581 359**	**2 052 567**	**2 137 340**	**2 548 094**	**2 880 641**
	(percentage)	***12.25***	***6.49***	***6.33***	***4.83***	***4.32***	***4.32***
European Union (Member Organization) (28)	(tonnes)	1 033 857	1 182 098	1 400 667	1 269 958	1 280 236	1 259 971
	(percentage)	*7.91*	*4.85*	*4.32*	*2.87*	*2.17*	*1.89*
Other European countries	(tonnes)	567 792	399 261	651 900	867 382	1 267 858	1 620 670
	(percentage)	*4.34*	*1.64*	*2.01*	*1.96*	*2.15*	*2.43*
Oceania	**(tonnes)**	**42 005**	**94 238**	**121 482**	**151 466**	**185 617**	**184 191**
	(percentage)	***0.32***	***0.39***	***0.37***	***0.34***	***0.31***	***0.28***
World	(tonnes)	**13 074 679**	**24 382 522**	**32 417 781**	**44 297 145**	**59 037 416**	**66 633 253**

Table 2.2: Aquaculture production by region: Quantity and percentage of global total production (FAO, 2014)

Across Africa many policy makers have placed aquaculture development high on their development agendas and strategic frameworks. International assistance has been requested to help develop the sector. Challenges hindering development of aquaculture is mainly tied to challenges and restraints namely: Water, land, financial, and support mechanisms needed for aquaculture production have become difficult to access as competition for these resources becomes tighter. These challenges are a threat to the sustainability to the aquaculture sector in Africa (FAO, 2014). Brummett, Lazard & Moehl (2008) state that evidence indicate that a pragmatic business approach supporting the development of SME's (small and medium-scale private enterprises) would improve and provide more benefits to aquaculture development in Africa in relation to centrally planned subsidized projects.

2.3.4 The status of Aquaculture Development in South Africa

South Africa's aquaculture development can be categorized into three epochs according to (Hinrichsen, 2007). Firstly during the colonial era the Europeans introduced exotic fish species which were used mainly for angling purposes. During the apartheid era in the mid 1900's the second wave of development were driven by supporting the private sector and establishing commercial aquaculture which were mainly focused on oysters and trout. The third post 1994 era were characterized by large scale commercial aquaculture (mainly marine and existing trout projects) and rural entrepreneurial projects. The development was however very restricted because government's provincial nature conservation departments changed policies that restricted production and stocking of exotic fish species. Government withdrew central support and privatized many facilities. After the political transition period government missed the opportunity to issue a national aquaculture policy and supportive frameworks which caused the country to fall behind in terms of global development.

Although aquaculture is outpacing all other food producing sectors as discussed in section 2.3.3. South Africa's aquaculture production is however highly undeveloped (Rana, 2011; Stafford, 2013) and responses to the rising demand for fish products have been slow in contrast with other parts of the globe (see figure 2.5). South Africa produced 4253 tonnes of fish and aquatic products (excluding seaweed) in 2010 (of which 2262 tonnes where freshwater fish)which is less than 1% of that what Egypt produces (Department of Trade and Industry, 2007; Rana, 2011; Statistics South Africa, 2013).

When compared to the rest of Africa, South Africa is not culturally a traditional fish eating nation - the indigenous people of Southern Africa do not share the same cultural preference to fish consumption (Department of Trade and Industry, 2007; Cilliers, 2013). South Africans that do consume fish and fish products have become accustomed to marine fish as part of their diet. Fish specifically the Hake species has been the common stock fish as these were plentiful and affordable. Hake resources have become overfished in the past decade. This led to strict management measures introduced in 2006. The South African pilchard, also a household name, and available on supermarket shelves throughout the country, has declined considerably and is classified as fully fished or overfished (FAO, 2014). The pressure on wild capture fisheries is too high to be sustainable as the sole resource of fresh fish. This calls for alternative fish resources such as aquaculture. The question is why aren't fish farms as popular and widely practiced in South Africa?

Some of the problems identified were the complex nature of aquaculture which requires a high level of management expertise and scientific skills, shortage of suitable sites and water availability, restrictive climate and legislative issues (Rana, 2011; Salie, 2014).

Aquaculture is not only seen as a tool to contribute to both food security and poverty and poverty reduction (Toufique & Belton, 2014) but commercial aquaculture development holds a great potential to contribute towards economic development and job creation in South Africa (Department of Trade and Industry, 2007). In common with many developing countries, South Africa does not yet have industry specific legislation and regulatory systems for aquaculture. Aquaculture is put in the same category as other food producing sectors and is controlled by generic legislation and guidelines (Rana, 2011).

The main reasons behind the slow development in aquaculture development are fourfold (Department of Trade and Industry, 2007; Rana, 2011; Salie, 2014):

- South Africa does not possess a native marketable-domesticated fish species;
- Policy which prohibited (until recently) exotic fish species to be commercially farmed (because of the possible threat to biodiversity and water pollution.);
- The South African extreme climatic and geographic landscape do not allow for favourable conditions that supports aquaculture development;
- There is inadequate technical knowledge, skills and production-related technology to aquaculture.

The progress and development of aquaculture has been restricted by environmental legislation on the conservation of natural resources of which much is cited in Section 24 of the South African Constitution. However, this is largely oriented to legislation focusing on natural resource oriented farming (traditional agriculture) but view aquaculture with other agricultural practices and in so doing inhibits aquaculture development and investment opportunity (Rana, 2011; Cilliers, 2013). One of the primary concerns identified was the regulation of alien and invasive species; because South Africa doesn't have marketable fast growing freshwater fish species and there was a great need to use them (Salie, 2014). The extent of impact of introducing alien fish species was not yet known and required impact assessments and in depth research (Hinrichsen, 2007). This long and strict process was however the most responsible way to protect our biodiversity and environmental sector for the long term's sake it can be argued that an open door could be given to innovative strategies such as the benefits of RAS (recirculation aquaculture systems) which is closed systems and pose no threat to biosecurity.

The Department of Trade and Industry (DTI) have embarked on a massive programme to support aquaculture development in South Africa through policies supportive strategies and cost sharing grants (Stafford, 2013). The sector has also been added to the Industrial Policy and Action Plan (IPAP) which aims to improve the productivity of the sector while generating job creation. The DTI and the Department of Agriculture Forestry and Fisheries (DAFF) launched the National Aquaculture Strategic Framework (NASF) in 2011 which supports aquaculture development and aims to guide the sector towards sustainable development. A R800 million support project Aquaculture Development and Enhancement Programme (ADEP) have been launched in March 2013 which aims to increase production, integrate industry participation, create and sustain jobs across the wider geographic spread of South Africa (Moolman, 2013).

On October 1, 2014 the Department of Environmental Affairs (DEA) promulgated the regulation of Prohibited Alien Species under the National Environmental Management: Biodiversity Act (NEMBA) 10 of 2004 which stated that a select invasive fish species would be permitted but regulated through permits and management guidelines (Department of Agriculture Forestry & Fisheries, 2013; Department of Environmental Affairs, 2014).

It can be argued that the new legislation and supportive frameworks marks the era of the fourth epoch of aquaculture development in South Africa which will dramatically contribute to the economy and national food security.

2.3.5 Tilapia: South Africa's next commercial fish?

The updated list of alien species under the National Environmental Management: Biodiversity Act allows for the farming of the Nile tilapia fish (Department of Water and Environmental Affairs, 2013),which is the world's second most commercially farmed freshwater fish species (see figure 2.8 and 2.9) and is widely known as the 'aquatic chicken' or the 'democratic fish' for its popularity amongst fish farmers, bland/non-fishy taste for culinary purposes and because it's considered as the perfect factory fish (El-Sayed, 2006; Rosenthal, 2011; Mapfumo, 2014).

Tilapia culture (the propagation/farming of tilapia fish) is believed to have originated 4000 years ago (El-Sayed, 2006). Tilapia is a native African freshwater fish, its name was derived from the African Bushman word meaning 'fish'(Trewavas, 1982). El-Sayed (2006) states that the tilapia fish have attributes that make it the ideal fish species for freshwater aquaculture, which is especially beneficial to developing countries. The beneficial factors of tilapia include:

- Fast growth;
- Resistance to stress and disease;
- Tolerance to a wide extent of environmental conditions;
- Quick adaptation and reproduction in captivity;
- Ease to adapt to low feeding levels and acceptance of various feeds.

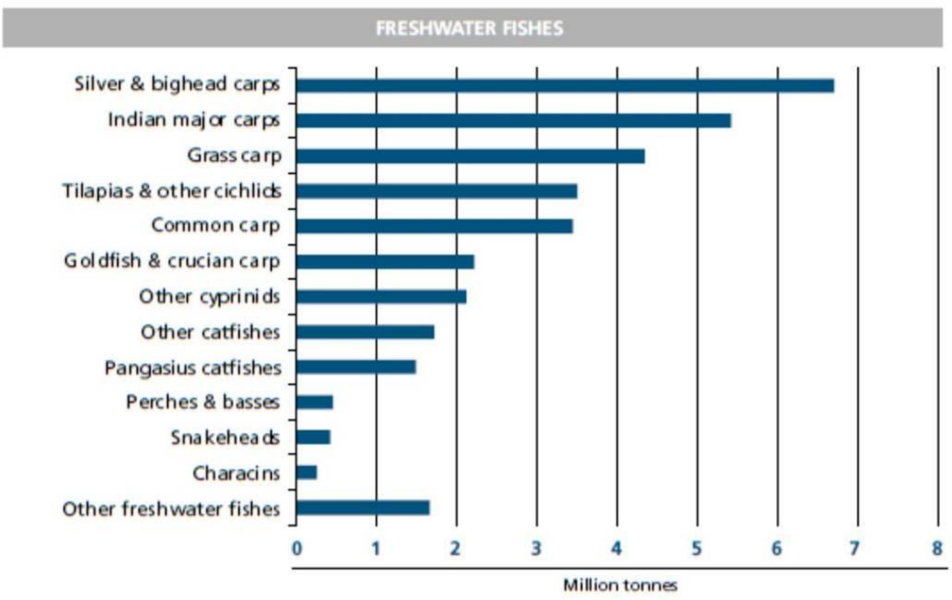

Figure 2.8: List of the major fish species in freshwater aquaculture in 2010 (FAO, 2012)

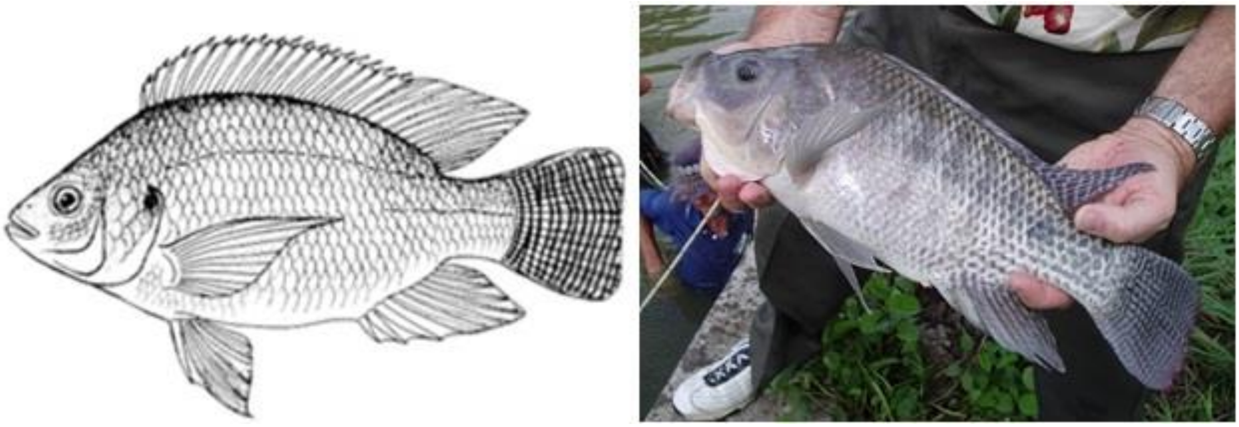

Figure 2.9: Image of Tilapia (Oreochromis niloticus)

The Nile Tilapia (Oreochromis niloticus) (see figure 2.9 above) is the most popular Tilapia species and is one of the most researched fish species making it a reliable fish species in aquaculture(El-Sayed, 2006). As with agriculture, successful development of the aquaculture sector is made up of a mix of indigenous and exotic breeds that are suitable for farming and able to adapt to unique challenges (Rana, 2011).

The Tilapia is characterised as being a very versatile fish as noted above, the most predominant constraint to tilapia culture, is its inability to withstand cool water temperatures. It is a warm water fish species that is most productive in the range of 29-33°C, the Tilapia can however survive in the range between 15 - 35°C (Popma & Masser, 1999). Tilapia is generally suited for warm lowland areas in South Africa which have warm summer and winter seasons such as Limpopo Province, North West, Mpumalanga and Northern Kwa-Zulu Natal. In areas which have winter temperatures too cold for Tilapia, production is advised to be restricted to warmer seasonal periods. This calls for research to explore production systems which can provide suited environments whilst being energy efficient and economically viable.

The Nile Tilapia species is not native to South Africa, as it is a North African fish. The Mozambique Tilapia (Oreochromis mossambiccus) is the widely found in South Africa and is commonly referred to as the Blue Kurper. The distinct difference between the Nile and Mozambique Tilapia species is that the Nile Tilapia species grows faster and larger and is the more researched specie which is commercially farmed between the two. The use of Nile Tilapia species in farming or research are however strictly regulated in South Africa through permits thus the reason that Mozambique Tilapia was used in the WAF experimental case study discussed in Chapter 4.

2.3.6 Challenges of Aquaculture Development

Mathias, Charles & Baotong, (1998) states that the predominant challenges to aquaculture are:

- Availability of water;
- Availability of land;
- Sustainability of feed;
- Complex scientific knowledge such as fish biology, and water ecology of aquaculture;
- Human carried viruses.

Aquaculture is mainly dependent on the 'triple bottom line of sustainability' for its own sustainability (FAO, 2010, 2014).The 'triple bottom line principle', was termed by John Elkington (Swilling & Annecke, 2012), that encapsulates the fact that for sustainable development planning, management and decision makers need to place social value and environmental value alongside economic value. Any threat to the economic, environmental and social cohesion supporting an aquaculture development will lead to challenges for the basic survival of the venture. To address or avert issues one has to identify them and construct an action plan. In identifying challenges and issues one has to outline on the various steps of production (figure 2.10) and look at the causes that inhibit successful aquaculture production.

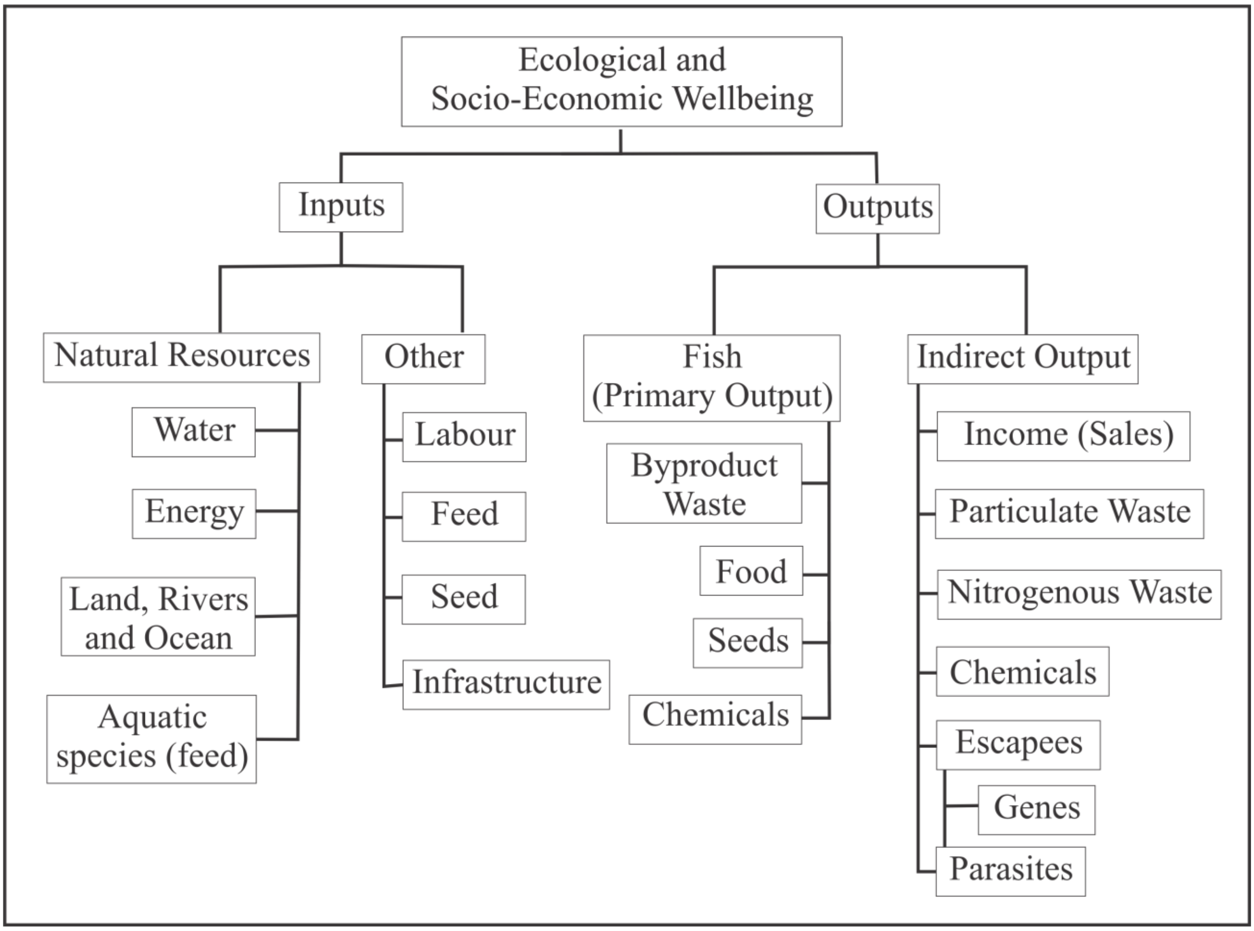

Figure 2.10: Schematic tree diagram to identify Ecological, and Socio-economic issues through the aquaculture production cycle (FAO, 2010)

An ecological assessment can identify and provide information about the ecological issues related to the aquaculture processes, as seen in figure 2.10; it can be broken into steps of production. It is often the case that the problems relate to social issues. If socio-economic issues arise then it is advisable to conduct a socio-economic assessment parallel to the ecological assessment.

Often both socio-economic and ecological issues have their origin in the ‘ability to achieve’ factor. The ability to achieve is held back by elements which have its origin in governance and institutional factors. Often the major problems to aquaculture development are that there is a:

- Lack of knowledge;
- Lack of training;
- Lack of enforcement and support;
- Insufficient enabling legal framework (FAO, 2010; Rana, 2011; Salie, 2014);

And it can be argued that another challenge is the lack of an integration of ecological, social and the ability to achieve factors. As identified above, knowledge and training is required for effective aquaculture development, this eventually lead to proper planning and capacity required to prevent projects from failing (Stoltz, 2010; Yeld, 2013; George, 2014).

For decision-making and prioritization it is recommended to track and place resource impacts into local, regional and global scale of impact and to categorize the impacts into negative and positive effects see table 2.3.

Issues at different scales	Farm (Local)	Regional Watershed	Global
		Resource Used	
Water	Use of water resource- Pollution of water resource through aquaculture effluent and potential antibiotics and medication. -Use water for aquaculture thus competing with other species on the farm that requires clean water. +Reclaiming of nutrient rich wastewater as crop irrigation +Using recirculating aquaculture systems that use water resources very effectively.	-Competes for water against other sectors that requires clean water. -Spread of polluted water and non-degradable chemical products. +If Aquaculture wastewater is cleaned and recycled it will have minimal effect on regional water systems. +Using recirculating aquaculture systems that use water resources very effectively leaving more freshwater for human consumption.	-Potential pollution of shared water bodies, and river systems +If aquaculture wastewater is reclaimed and recycled the pressures for global freshwater supplies can be relieved. +Using water efficient recirculating aquaculture systems which produce food with low water footprints.
Energy	- Energy used for production (pumps, aerators) -Farming with the wrong kind of fish species which requires a high energy input.	-Energy used to transport product to local market. +Using renewable energy sources and energy efficient farming methods and modes of transport will reduce the energy demand on the electricity grid and reduce the carbon	-Energy used for transport (fuel, and cold chain energy). +Using energy efficient transport modes or supplying local will reduce the environmental impact of the end product.

	+Farming with a native fish species which are adapted to the local climate and requires minimal energy input. +If renewable energy and energy efficient farming methods are used it will relieve the pressures of external energy input which may cut costs and lower the carbon footprint of fish.	footprint of the farming operation.	
Species	-Escapee fish that might interbreed with native fish species and cause disease. +Farming with own hatchery supplying own fingerlings instead of wild capture.	-Using feed that is sourced from other fish resources may have an indirect negative impact on the fish stock and sustainability of the ecosystem. -Escapee fish that might interbreed with native fish species and cause disease.	-Using feed that is sourced from other fish resources may have an indirect negative impact on the fish stock and sustainability of the ecosystem. +Using sustainable feedstock +Farming with own hatchery supplying own fingerlings instead of wild capture.
Land, River, or Ocean Space	-Using up space with a poorly designed system and causing a direct influence in the area. +Using efficient and well-designed farming systems which are compact. +Using closed recirculation technologies which can be used without the need for large water bodies.	-A farming operation which takes up too much space, which may displease local residents or fellow water users. -Non-rehabilitated fish farms which cause harm to water users and ecosystems (nets, equipment).	

Table 2.3: An example of categorizing impacts of aquaculture (Aquaculture Division, 2007; FAO, 2010; Salie, 2011).

Table 2.3 above maps out the most common resource use issues that are caused by aquaculture, the farm is however part of a complex ecosystem and thus input and outputs have to be analysed (see figure 2.10, 2.11 and 2.12). A farmer has to map out and weigh the negative and positive effects to determine and simulate the impact that it would have. The farmer or developer can thus put measures in place to minimize or avoid these effects.

Negative and positive impacts of resource use should be seen as a whole in the broader context of the environment.. It will not be sustainable for an aquaculture venture to be only socio-economically positive and have no measures in place to deal with its environmentally negative challenges. Impacts and risks should be categorized into short, medium and long term facets (FAO, 2010).

One of the major environmental risks identified in intensive aquaculture systems is the pollution of water resources through the production of waste water which is high in nutrients which causes eutrophication (algal blooms in water) which causes degradation in water quality and loss of aquatic life (Fisheries Branch Of The Department Of Agriculture Forestry and Fisheries, 2013).

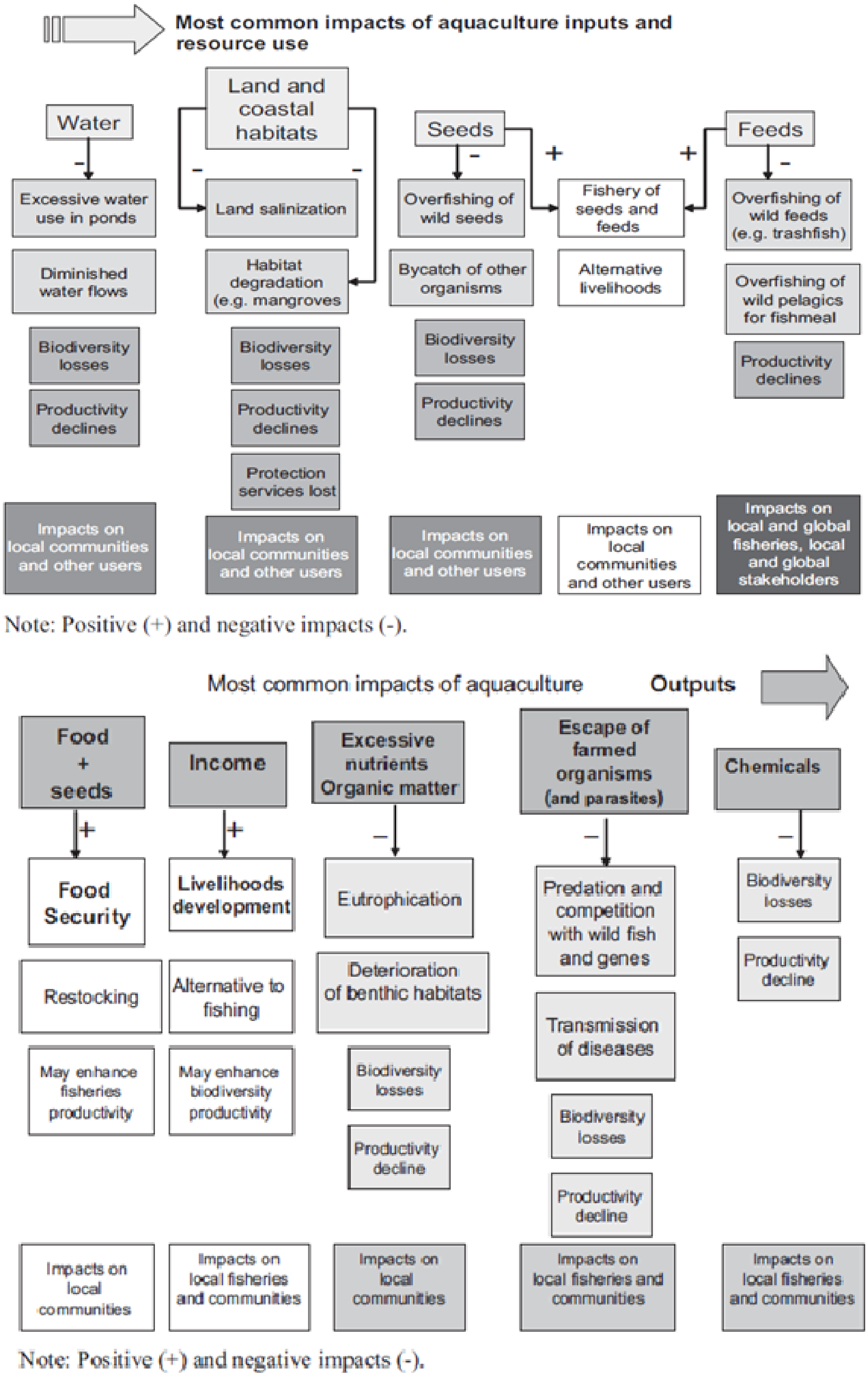

Figure 2.11: Common issues with aquaculture inputs and outputs (FAO, 2010)

Rana (2009) warns of fish farming ventures that fail because of low-value fish species being used that make projects economically unfeasible. Lapere (2010) argues that if a faster growing species of tilapia were to be used in aquaponic systems namely the “Nile Tilapia” species, it would significantly benefit the economic feasibility of aquaponics, this is mainly due because as other RAS technologies, aquaponic systems rely on costly infrastructure. It is thus an ideal opportunity to explore the viability and business plan by using the faster growing Nile tilapia in aquaponic systems.

According to Mapfumo (2014), aquaculture development is challenged by climate related issues such as flooding, drought and climate change. Project finance is difficult to access as banks and professionals have limited knowledge of aquaculture and many projects have unrealistic business plans (Salie, 2014; Stander, 2014). Aquaculture development is further challenged by the food markets as aquaculture has to compete with other agricultural sectors such as chicken farms and horticulture.

Hinrichsen (2007), states that aquaculture development in South Africa is determined by the successful and efficient integration of natural resources (land, climate, energy and biodiversity), human resources (skills, technology and labour) and economic resources (capital, market access and infrastructure). This approach is in line with the Triple Bottom Line approach of sustainable development

Risk assessments (see figure 2.12 below) and environmental impact assessments (EIA’s) sometimes seen as a possible barrier to development but it is a fundamental part of South African regulating policy that maintains and regulates the sustainability of our environment. Environmental assessments are just one part of the Triple Bottom Line approach as required for the integration of ecological, social and the ability to achieve factors that determines the overall sustainability of projects. It is Using simple tools to assess risks and challenges will enable developers to avert risks through design and decision making (Salie, 2011). Stated by the new NEMBA and AIS regulation it requires EIA’s which is determined by the extent of the risk if written proof of exemption can be received only a risk assessment is needed (see figure 2.12) followed by an Environmental Management Programme (EMP) (Department of Agriculture Forestry & Fisheries, 2013). The National Environmental Management: Biodiversity Act states that for aquaculture projects to receive permits essential steps is to be taken to minimize risk to biodiversity and to reduce the impact on the environment (Department of Water and

Environmental Affairs, 2013). According Leung et al. (2002) preventative measures are the most effective way of control.

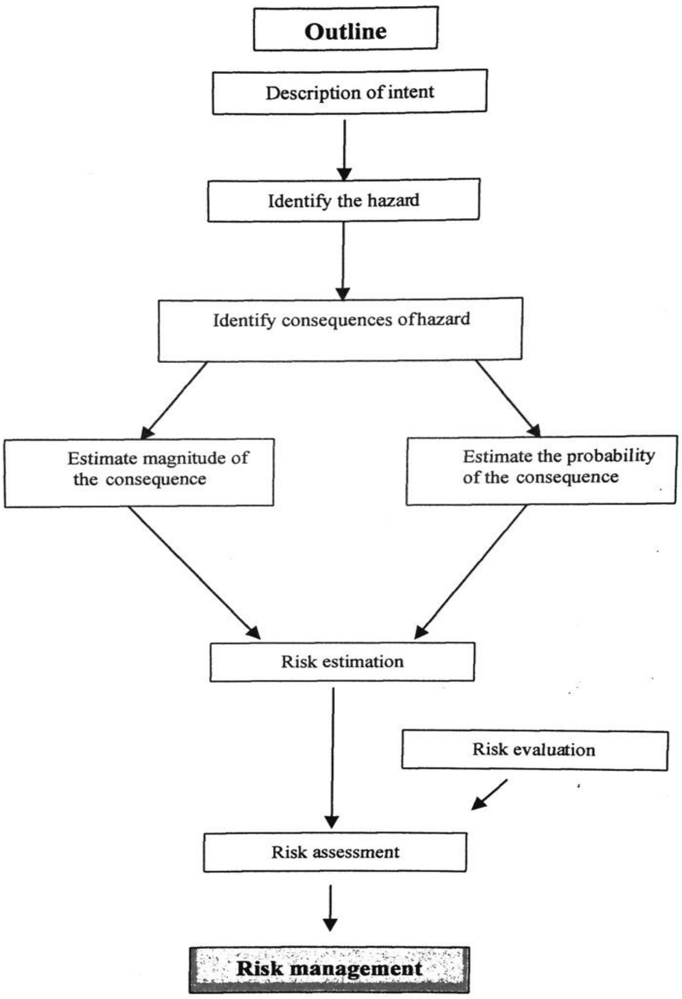

Figure 2.12: Risk assessment and management toolbox for Aquaculture systems (Salie, 2011)

Freshwater fish like the tilapia can be produced in seasonal pond culture, seasonal cage culture in dams or rivers, or in intensive RAS systems in tanks and raceways. Tilapia is mainly restricted to seasonal open pond farming due to the climate restriction (Fisheries Branch Of The Department Of Agriculture Forestry and Fisheries, 2013). RAS systems which is more expensive due to additional infrastructure can be more productive in the South African environment because and year round production and compliance with legislation. The Department of Environmental Affairs (DEA) & Development Planning guidelines encourages the use of closed recirculation facilities which treat and recycle water to prevent biosecurity risks like the discharge of waste and problematic organisms into the external environment (Hinrichsen, 2007).

It can be argued that innovative approaches to aquaculture such as the use of closed RAS systems can be considered in line with legislation and sustainable environmental measures in which it addresses many issues identified such as biosecurity, resource use efficiency and waste water recycling. RAS systems and alternative methods require to be further researched to identify the benefits it holds for a sustainable aquaculture industry.

2.3.7 An Alternative Approach to Aquaculture

Fishing activities, be it from rivers, dams, or oceans, have been a major source of food, employment and other economic activities since ancient times. By gaining knowledge of the complex science of fish and understanding the dynamic environment of fisheries and aquaculture, humanity have learned that fish resources although renewable, are not infinite as is the case in many over-exploited capture fisheries in the world. Aquaculture thus have to play a role to alleviate the pressure on capture fisheries and require sound management for it to sustainably supply the world with economic, social and nutritional well-being (FAO, 2010).

Profitability remains the prime motive for aquaculture ventures thus a business friendly approach and supportive policies by government will greatly benefit aquaculture development. The social licence of aquaculture entails considering the wider society's acceptance of the aquaculture development as well as the impact it has on the community. Environmental integrity is determined by mitigating the possible negative impacts the aquaculture development has on the environment so that the farmer and later generations can continue with the same activities on the specific site over a long period of time. The growing trend of consumer choice also influences the farmers to supply ethical and sustainable farmed products (FAO, 2014).

The triple bottom line of sustainable development is recognized as the principle goal for sustainable aquaculture governance (Hinrichsen, 2007; Khan et al., 2009; FAO, 2014). For sustainable development of aquaculture it needs to entail economic viability, social responsibility, environmental integrity as well as realistic technical feasibility.

The lack of adequate freshwater resources, suitable space for aquaculture, and concerns over pollution are considered key drivers for recirculating aquaculture as these obstacles restrict the development of conventional flow-through systems and cage culture farming (Mathias, Charles & Baotong, 1998; Badiola, Mendiola & Bostock, 2012).

Salie (2011), argues that untreated aquaculture effluent can cause harmful environmental problems like sedimentation and algae blooms. Using chemicals such as antibiotics and pesticides may lead to a loss in flora or fauna downstream. Escaped organisms may pose a threat to biodiversity of fauna and flora.

The proposed methods to reduce the environmental effects of aquaculture effluent:

- Sound management practices such as feeding, disease control;
- Better area selection;
- Sediment collection;
- Collection of dead fish;
- Recirculating systems.
- Improved biosecurity.
- Integrated/poly-culture (the culture of five or more species of fish in the same pond, to create an integrated symbiotic environment of increased production (Mathias, Charles & Baotong, 1998).

The FAO Fisheries Glossary (Crespi, 2008:119) defines integrated farming as: “an input from one subsystem in an integrated farming system, which otherwise may have been wasted becomes an input to another subsystem resulting in a greater efficiency of output of desired products from the land/water area under a farmer’s control.” Integrated aquaculture is thereby defined as, “an aquaculture system sharing resources – water, feeds, management, etc., with other activities; commonly agricultural, agro-industrial, and infrastructural.” Polyculture is defined as “the rearing of two or more non-competitive species in the same culture unit (Crespi, 2008:18;238).”

Integrating aquaculture is a great way to deal with external and internal issues. It offers advantages that help control environmental quality on land and water bodies and it helps with the functions of bio security measures. For centuries rice farmers in Asia have benefited from integrated agriculture-aquaculture. Where they would have only been supplied with rice, by integrating and providing an environment for aquatic animals they are additionally supplied with protein and other nutrients for a balanced diet (Mathias, Charles & Baotong, 1998; FAO, 2010).

Mathias, Charles & Baotong, (1998) acknowledges that food security implies that food be produced at an affordable rate for the poor of society. The authors argue that integrated farming makes it possible for small farmers to produce inexpensive fish and crops.

Conventional aquaculture development often affects other socio economic human activities like agriculture, urbanization, industry, as well as fisheries. To reduce the effects that individual activities have on the environment, some activities can be integrated with others. This can be done where activities share similar resource flows or when activities find mutual benefits in each other's processes. Integrating water bodies of different aquatic activities can be done to achieve a beneficial balance that reduces the pressure on the environment as well as increasing the resource efficiency of the activity (FAO, 2010).

It is recommended that aquaculture effluent be treated by using:

- System integration and water recycling technology;
- Site rotation for cage farming;
- Use of "green infrastructure and design";
- More efficient use of input resources;
- Improved management techniques

Integrated aquaculture is considered an effective way to mitigate environmental challenges. In Asia many rice and freshwater fish farmers have adopted integrated multi-culture and partitioned aquaculture systems to increase their resource use efficiency and reduce their impact on the environment. Although integrated aquaculture is mainly seen as a mitigation approach to manage excess nutrient rich effluent and organic matter, methods like integrated multitrophic[7] aquaculture (IMTA) proves to be very productive (FAO, 2010).

An IMTA project in Canada have been studying the multitrophic Atlantic salmon cage farming that is integrated with Kelp and mussel culture. It was found that there was about a 50% increase in the growth rate of the kelp and mussels that were placed near the salmon cages, this is due to the nutrient availability that are supplied by the salmon waste (FAO, 2010). This integrated aquaculture method works efficiently because mussels (classified as bivalves/shellfish) are biofilters and consume particulate waste from salmon, and the kelp consume the left over dissolved nitrogenous waste.

2.3.8 Aquaponic farming

Aquaponic farming is the combined culture of fish and plants in recirculating systems, where both organisms are co-dependent on each other. Aquaponic systems are integrated aquaculture

[7] Across species with different feeding levels and characteristics but of same food chain

systems that recirculate water and produce plants without soil (hydroponics) (Rakocy, Masser & Losordo, 2006). The link from aquaculture to hydroponics are found in the nutrient requirements of hydroponics which in conventional hydroponic systems use chemical fertilizers but in aquaponic systems obtains nutrients from the nutrient rich water of aquaculture waste water (Childress, 2002).

Aquaculture effluent contains 10 of the 13 required nutrients in adequate quantities that plants require to grow, Ca, K, and Fe are the only nutrients that need to be additionally supplemented (Rakocy et al., 2004). The amount nutrients supplied by the fish are directly related to the amount fish eat as it is their waste and thus the fish feeding ratio determines the amount of plants that can be grown (Rakocy, 2007; Lennard, 2012). In itself aquaponic systems without additional (Ca,K,Fe) supplementation are able to support healthy growth of leafy plants such as lettuce, spinach, and basil as the main requirement for them are nitrogenous (NO_3) which are the main supplied nutrient of aquaculture effluent, (this is the reason why leafy plants were selected for the WAF) (Kempen, 2012). Fish fed a normal diet will produce a continuous supply of nutrients to supply leafy plants to grow optimally and the plants will prevent any nutrient build up by taking up nutrients for growth and in return this reduces polluting discharge into the environment (Rakocy et al., 2004).

Aquaculture produces a build-up of toxic waste which is broken down through a biofiltration process to non-toxic soluble nutrients; these soluble nutrients are used by plants for growth and development. The water that reaches the end cycle has been cleaned and is then pumped back to the fish tanks (see figure 2.13). A well balanced and managed aquaponic system will enable no excess nutrient build-up in the water (Blidariu & Grozea, 2011).

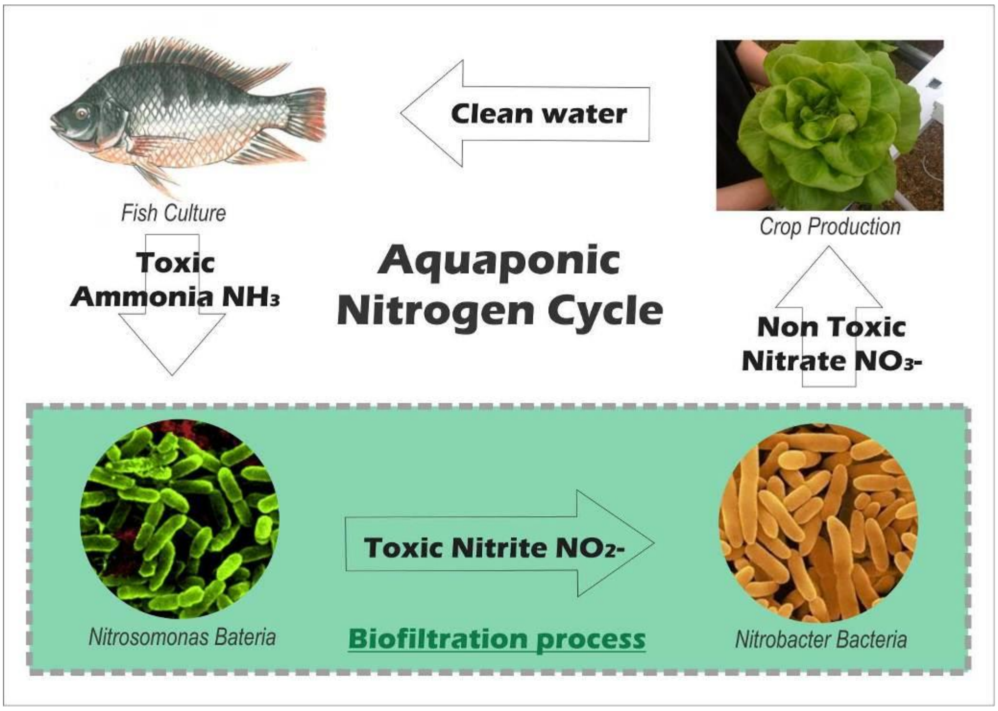

Figure 2.13: Nitrogen cycle and water filtration in Aquaponic systems.

A study by Moore, (2014) found that aquaponics is a very water efficient method to produce protein producing 0.050g of protein per litre water used which is more effective than that compared to produce vegetables (see figure 2.14 below).

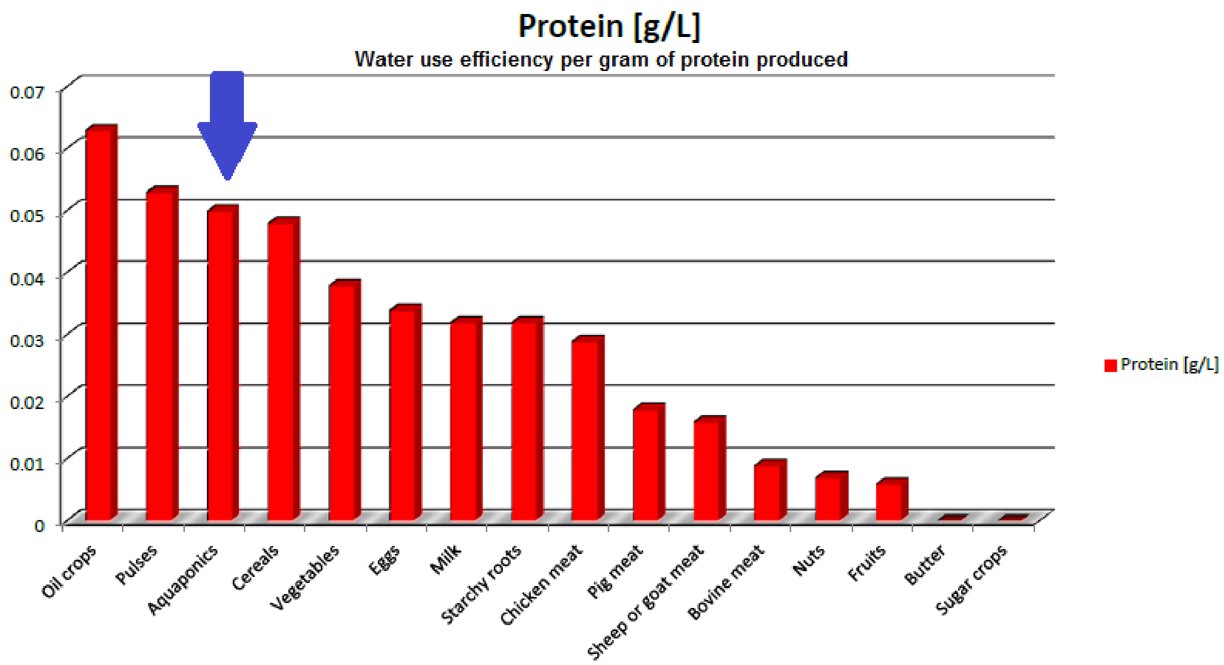

Figure 2.14: Water use efficiency per producer of protein, (Moore, 2014)**.**

In South Africa which is a relatively water scarce country the water use efficiency in the agricultural sector will play a crucial role for sustainability as agriculture consumes 62% of the national allocation of water (Department of Water Affairs and Forestry, 2010). Aquaponics can be viewed as a food producing technology which is highly resource efficient to produce high quality nutritious food in areas with water scarcity.

Aquaponics, if properly managed, can produce large quantities of fish and plants and can treat toxic effluent very efficiently (Rakocy, Losordo & Masser, 1992). Dissolved nutrient rich (toxic) waste produced by cultured fish is treated by bacteria and nitrification of a biofilter which transforms toxic waste into soluble nutrients required by the plants. Furthermore the plant's root zone plays an important role in improving the water quality by nutrient removal as it is required for growth see figure 2.13 (El-Sayed, 2006).

The only waste product that aquaponic systems have is when particulate waste and nontoxic nutrients accumulate which can be filtered out, removed and used for tertiary crop production as composting or as high quality irrigation water. There is a potential to incorporate freshwater bivalves and bottom feeder aquaculture species to remove particulate waste to further increase production and reduce the environmental impact.

Research carried out by Dr James Rakocy at the University of the Virgin Islands on understanding and improving aquaponic systems highlighted that the research and development done plays a major role in the success of many aquaponic systems worldwide (El-Sayed, 2006). In the past two decades interest in aquaponics has gained tremendous momentum as the internet made it possible for information to be accessed widely. Schools in the US have included aquaponics in their science curricula, many aquaponic suppliers and support structures have sprung up, research projects and short courses have been introduced by Universities, small back yard systems have been widely built and a number of large commercial operations have been developed (Rakocy, Masser & Losordo, 2006).

Tilapia especially the Nile tilapia specie is considered to be a good fish of choice for aquaponics because it is a marketable fish, it is fast growing, it produces high levels of ammonia required for nutrient supply for plant production and the specie is resistant to stress in comparison to most fish species (Mathias, Charles & Baotong, 1998; Childress, 2002; El-Sayed, 2006; Rana, 2011; Rosenthal, 2011).

2.4 Conclusion

Land, food and water resources are identified as become increasingly important under increased population growth. It is realized that the issue is going to become an increasing urban challenge.

People remain malnourished although there is enough food available, this call for more nutritious food to be produced and given access to people.

Fish is identified as an extremely healthy food source which has the potential to provide a well-balanced diet. It is recommended to consume a variety of marine and freshwater fish food good health. Aquaculture is identified as a sector which is very highly undeveloped in South Africa with a large potential to contribute to food security, job creation and economic development.

It is argued that aquaculture development has entered the fourth era of development as that there is an enormous amount of energy put behind aquaculture development in South Africa backed by government. The South African government has promulgated new regulations which allow for the introduction of exotic commercial fish species under regulatory measures which do support the biodiversity protection of local environment.

The Nile tilapia fish species is a good candidate commercial fish for South Africa with beneficial physical characteristics for farming in South Africa. The challenging factors that restrict aquaculture development are predominantly land and water availability, the lack of human capital, unsuitable climate and biodiversity protection measures.

It is identified by approaching resources in an integrated fashion, such as a triple bottom line approach, aquaculture development have a higher chance to be successful. Integrated aquaculture and RAS are methods which have this approach which are argued to be a good approach to aquaculture development.

Aquaponics is the integration of aquaculture and hydroponics which is a highly resource efficient method to integrate food production and waste systems. It is argued that aquaponics will prove to be a good alternative to South African aquaculture development as it deals with several resource challenges and complies with new regulations.

Chapter 3 –Proposed approach to Integrate Aquaculture and Crop Production

3.1 Introduction

This chapter will review and discuss the literature and aspects of how to integrate aquaculture and hydroponics through understanding the fundamental aspects of both technologies. This will be done through the approach of breaking down the sub-sectors of how aquaculture and hydroponics individually functions and finding the links to integrate the technologies. Understanding the discussed sectors will enable a better understanding of the overall performance of aquaponic farming.

As discussed in the prior chapters, the development of aquaculture holds great capacity to supplying high quality food to our people, employ workers and to improve the economy. Because of the scientific nature of aquaculture and hydroponic farming a high level of management expertise is required to sustainably manage the integration of these technologies. Capacity building and knowledge is thus required to understand each management practices. To successfully manage aquaponic systems it is advisable to optimally manage both hydroponic and aquaculture processes according to standard production techniques.

It can be argued that a common issue aquaponic farmers encounter is that they have a primary production focus incorporated in their management, design and inputs of their systems, in other words they focus on producing plants disregarding the optimal conditions required for rearing fish or vice versa. The approach towards aquaponics has to be a bilateral focus to produce both plants and fish in optimal conditions.

3.2 Methodology

For the case study discussed in chapter 3 and 4 I consulted the literature from classwork and extended research on aquaculture and hydroponic greenhouse production and management techniques and used the WAF as experimental case study. The theoretical research and classwork enabled me to gain knowledge to put together chapter 3 which is aimed to deliver a management approach to aquaponics through recommended management techniques of aquaculture and hydroponic greenhouse production and management. Chapter 3 was done prior to chapter 4 to provide the theoretical background needed to understand chapter 4.Chapter 4 was a physical case study conducted to determine a recommended approach to aquaponics management and design principles. Most of the design data used to design the WAF was derived from work done by Dr James Rakocy and Dr Wilson Lennard from the University of the Virgin Islands, Dr Jason Licamele from the University of Arizona, and Philippe Lapere from the University of Stellenbosch (Rakocy, Masser & Losordo, 2006; Licamele, 2009; Lapere, 2010; Rakocy & Lennard, 2013).

The WAF is comprised of three individual +- 10 000L aquaponics circuits which contain fish and plants. The fish are reared in tanks and the plants are grown in rectangular grow beds inside the greenhouse. The plants grow from the nutrients supplied by the fish.

The approach of this case study was not to measure input costs, marketability or to produce optimum fish or plants but to feed only the fish and maintain a basic 2% of bodyweight optimum fish diet and grow a selection of crops and herbs from the nutrients provided from the fish. This was due because the focus was on the system components, management principles and the concept development itself. One of the focus points was to participate in the daily management of an aquaponics system and observe the outcomes and performance of:

- The system design as a whole;
- Fresh produce quality;
- Fish behaviour;
- The different growing mediums;
-

This approach gave me a bigger insight on how the various components of the system functioned. Studying the design, construction, challenges and behaviour of a system like this was needed to add to the learning process and add to the recommended uses described in chapter 3 and 4.

3.3 Aquaculture Management

3.3.1 Basic Aquaculture Production Techniques

Physiological and biological needs

To be able to understand aquaculture the basic physiology and biological requirements of the fish needs to be understood. In order to maintain healthy and productive fish in a system an optimal environment for the fish has to support its physiological and biological requirements. As it is with any successful farming sector the farmer aims to produce the best quality product possible, to produce high quality aquaculture products a fish farmer has to full know the external and internal anatomy of the fish and know what signs to look for when a fish is sick or behaving unusually (see figure 3.1,and 3.2). The nature of aquaculture is that fish are living in water; the water environment poses unique challenges to the anatomy and biology of fish other than that of terrestrial beings.

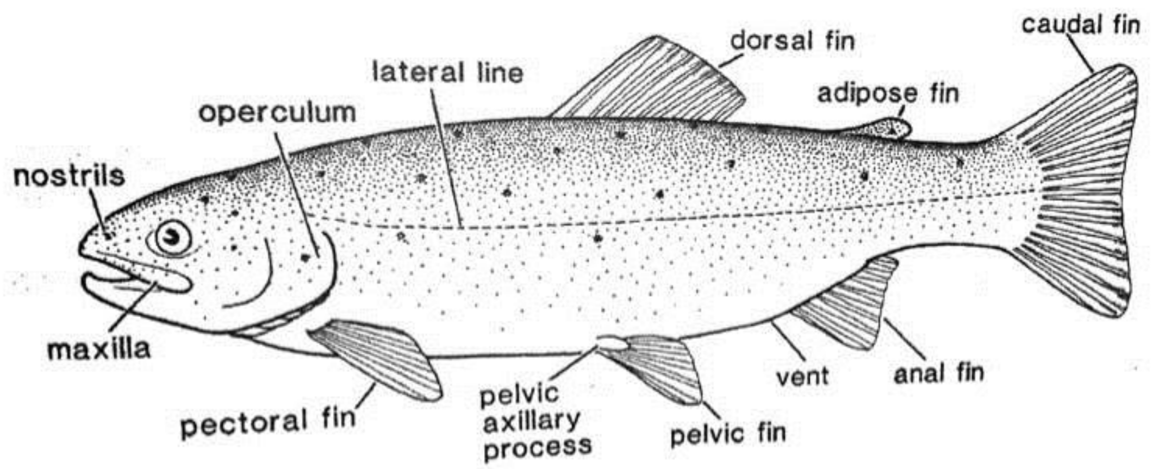

Figure 3.1: The external anatomy of a trout (Brink, 2011)**.**

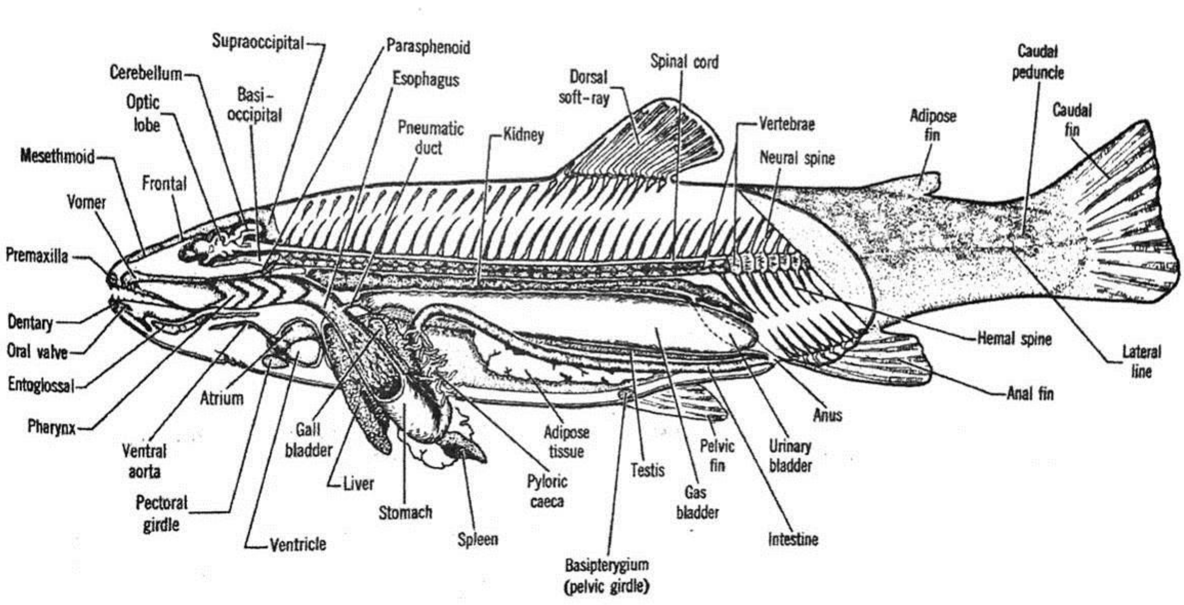

Figure 3.2: The external anatomy of a trout (Brink, 2011).

A fish has to deal with 4 challenges namely:

- Ensuring mobility in a water environment which are 800 times denser than that or air;
- Facilitating osmoregulation and management of bodily functions in fluctuating chemical environments;
- Enabling respiration in an environment which have far less oxygen than that on land;
- Maintaining and regulating thermal regulation and maintenance of bodily functions (Brink, 2011).

If the above named challenges could be reduced and be provided to the requirements of the specific fish the fish would thrive. There are also factors that influence a fish's growth ability namely the fish's:

- Age (younger fish have a faster growth rate and slows down as the fish matures)
- Genetic factors (some genetic strands are more superior in terms of growth performance);
- The external seasonal and temperature factors;
- And other internal biotic factors such as competition, hormones, and induced stress (Brink, 2011; De Wet, 2011).

To enable a fish to grow and maintain a healthy condition the above factors needs to be managed and understood. The farmer also has to know that the fish require different diets though their growth cycle. The nutrient content varies according to different fish growth stages. Smaller fish usually require higher protein content than that of mature fish. A farmer should do research and purchase the required feed.

One of the primary requirements to sustain energy for the life of a fish is the supply of and management of oxygen. The oxygen use efficiency is determined by the ability to effectively obtain oxygen from an external environment and to disperse it into bodily tissue (Brink, 2011).

The oxygen consumption of fish which determines the dissolved oxygen levels of the water and indirectly the carrying capacity of fish is influenced by its metabolic factors such as:

- Water temperature, higher water temperatures lower oxygen saturation capacity;
- Age, Oxygen consumption increases as the fish ages but decreases once maturity is reached.
- Activity levels, the fish's oxygen consumption is directly influenced by its activity levels;
- Size, larger fish require more oxygen;
- Nutrition, feeding fish increases metabolic activity which increases oxygen consumption
- Reproductive rate, oxygen requirements increase as fish enters reproductive processes.
- Blood pH, a lower pH reduces the oxygen carrying capacity of red blood cells;
- Blood CO_2, a higher concentration of CO_2 levels reduces the ability to absorb oxygen into the red blood cells (Brink, 2011; Salie, 2011).

Nutrition and digestive system

Aquaculture feed remains the 'holy grail' to profitability and sustainability of aquaculture projects as it makes up the majority of farming input production costs (De Wet, 2011). It is recommended that farms secure trustworthy local feeds or manufacture their own (Mathias, Charles, Boatong , 1998; Mapfumo, 2014).

As with all other animals, fish primarily eat to satisfy their energy requirements. They require nutrition for growth, maintenance and reproductive processes. Fish feed accounts for the largest input production cost in an aquaculture system. Feed could account for between 40-60% of total operational expenses. The efficiency of feeding is therefore a critical factor to the profitability and sustainability of an aquaculture enterprise.

Fish can be fed through manual hand feeding, automatic feeders or demand feeders. Feeding should be performed at optimal levels for fish to reach its genetic growth potential; underfeeding would lead to loss of potential, stress and disease and over feeding would lead to wasted and poorly utilized feed resources as well as water quality issues. Overfeeding could also result in a:

Drop in dissolved oxygen levels which is caused by the high metabolism rate of the fish and the decaying organic matter of leftover feed; secondly overfeeding could also result in a rise of CO_2 and dissolved nutrient compounds. And finally it could reduce water visibility through a rise in dissolved solids and total suspended solids.

Water quality levels needs to remain optimum for fish see their food (that determines steady fish growth) and to enable healthy osmoregulation. To clean water requires a constant flow of fresh water which are not always available or the most sustainable method, or water can be recirculated and filtered with a well-functioning biofilter which enables the breakdown of toxic nutrients to nutrient that are able to be utilized for irrigation or in aquaponic systems which is thus very beneficial and efficient to manage water quality and to utilize nutrients, producing two products with the same inputs.

Fish feed needs to conform to the dietary, nutritional requirements of a fish as well as support the physiological aspects and feeding habits of a fish. It is important to understand the feeding habits of fish for good management and proper feeding. Feeding habits are classified according to the species: Predators, Grazers, strainers, parasites and suckers (De Wet, 2011).

Fish have different energy requirements which should be maintained at optimum levels to develop efficiently. Factors that influence the energy requirements are:

- Water temperature;
- Water flow rate;
- Water quality;
- Feeding level;
- Physical size of fish;
- Light exposure;
- Physiological status of fish;
- Stress levels experienced by fish;
- Dissolved oxygen levels in water.

The efficiency of fish feed can be determined by calculating the feed conversion ratio[8] (FCR) (De Wet, 2011):

$$FCR = \frac{Feed\ fed\ in\ dry\ weight\ (kg)}{Wet\ weight\ gained\ (kg)}$$

To understand the feeding behaviour a farmer can analyse and improve each step of the feeding process to ensure optimal feeding for growth takes place see figure 3.3.

The feeding cycle starts with stimulating the appetite of a fish. A farmer aims to provide an environment for their fish which is near ideal for the fish to have a healthy appetite to grow and develop as fast as possible.

A fish's appetite is influenced by:

- The oxygen availability in the water;
- The water temperature;
- The ammonia levels in the water;
- The amount of competition for food between other fish;
- The amount of stress the fish experience (De Wet, 2011; Salie, 2011; Stander, 2014).

The hunger stimulus will enable a fish to eat, as it is controlled the appetite (see figure 3.3). Feed identification is important, a farmer needs to understand and take into account what chemical and physical traits the fish feed has and what works best for the fish. Feed can be manipulated by enabling them to float or sink, giving them a specific taste, colour, and contrast. The physical size and form of the feed particle is also important. The recommended fish feed is a pellet that is a one quarter the size of their mouth size. Feed that is too big for fish to swallow will be wasted or leach nutrients as it lies uneaten causing water quality degradation.

[8] It is s a measure of an animal's efficiency in converting feed mass into increases of the desired output.

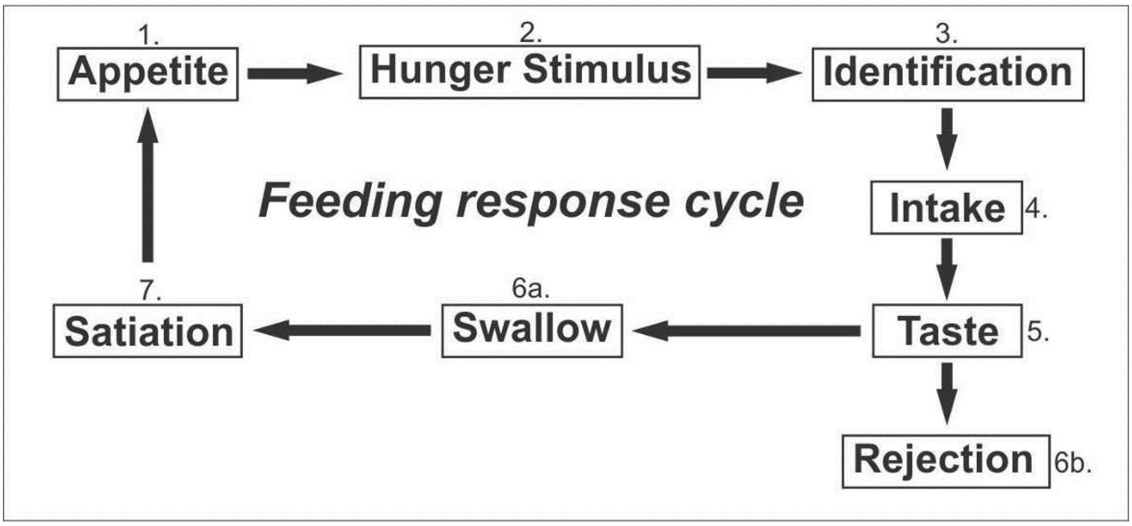

Figure 3.3: Summary of the feeding response cycle (De Wet, 2011)**.**

The fish can either eat or reject feed (after making an effort to taste or bite the feed) which will indicate a problem with the feed itself. A good farmer needs to monitor the feeding behaviour of his fish and ensure that the fish are well conditioned to proper feed.

When the fish has satisfied its energy requirements it will stop feeding. This is the appetite which is regulated by the stomach; the expanding and emptying of the stomach and the other appetite factors will control the feeding ability of fish.

Osmoregulation

Freshwater fish get rid of minerals and pass water through their gills (located under the operculum in figure 3.1). The fish has to regulate its internal mineral content for balance called homeostasis[9]. The fish excretes waste which is mainly nitrogenous in the form of ammonia; ammonia has to be excreted regularly as a build-up can be toxic to fish. The bulk of nitrogenous waste pass through the gills, only 2-25% of the waste passes through the urinary tract.

Stress Management

Fish stress is usually induced by its environment and can be caused from natural or man induced events, they influence the behaviour, the disease susceptibility of fish and are usually a primary cause of fish fatalities.

Stress can be managed by controlling stress causing factors like:

- Rapidly fluctuating water temperatures. Temperature is important as it has an effect on the amount of oxygen that can be carried by water. Temperature also has a direct

[9] The tendency towards a relative stable equilibrium between independent elements, especially as maintained by physiological processes.

influence on the metabolism of a fish, for the fish to achieve the maximum FCR and growth the temperature should be in the required temperature.

- Rapidly fluctuating dissolved oxygen and pH levels
- An increase in chemical substances in the water such as Copper, NH_3, H_2S and CO_2
- A TDS and/or TSS in the water that are too high (0-80 mg/l for inorganic material and 0-30mg/l for organic material) for fish to see food, thus leading to inefficient eating, changed behavioural interacting with other fish and physical irritation that could lead to disease (De Wet, 2011; Salie, 2011).
- High stocking density; this varies from specie to specie. The primary problem of a high stocking density is oxygen shortage in water. Stocking density can be increased by increasing the dissolved oxygen in the water.
- Bad feeding management; fish feed on the basis of meeting energy demands. Energy makes all life and development possible thus it is important to maintain healthy energy levels in farmed fish. The fish's appetite is controlled by factors namely: oxygen and temperature, ammonia levels, physical handling and competition amongst fish. It is important to maintain the required environment for the fish to enable it to maximize feed consumption, growth and efficient feed conversion (De Wet, 2011).
- Inadequate water flow and circulation. Because fish vary from species they have adapted to different environments and thus they also require unique environments. Water flow provides a fresh supply of oxygen and food which the fish needs for to support living functions. However if the water flow is too high the fish have to put much effort and energy into swimming and against the current which can stress the fish lead to secondary problems like slow growth and disease.
- Hierarchical structure in the water. Fish doesn't always grow on the same rate and are not always the same size. Bigger and more aggressive fish tend to dominate smaller fish in terms of access to food and reproduction. Fish need to be graded to size regularly to maintain fish that are not more than 1.5 times the size of other fish (De Wet, 2011).
- Fright and noise from farmer or farming environment. Fish require an environment which resembles their natural habitat. Their environment at the farm requires not to be stressed by loud noises or external factors which may stress the fish into hiding or no feeding.
- Predators; often cormorants, otters, birds of prey and even poachers is usually associated with noise and frightening experience for fish which can cause stress to fish. A farmer is thus required to prevent predators from accessing the fish.

3.4 Water Management

3.4.1 Aquaculture Production Systems

According to the Aquaculture Division, (2007) and Lekang (2007) fish are usually bred in three types of production systems namely:

- Extensive production systems, it is characterized by often being informal low stocking density systems. Most extensive systems are usually cheap earthen ponds. Fish usually feed on natural organisms or organisms which are developed by spreading organic matter such as manure and inorganic fertilizers on dams to enrich the water.

- Semi intensive production systems are systems which depend on the natural productivity of ponds. It has higher stocking densities and is fed artificial diets as food supplement.

- Intensive production systems usually have high stocking densities and it monitors and administers a balanced feed. The focus is on production and the system is efficiently used. Examples are, tank culture, floating cage systems, linear race ways and intensive dam culture.

According to Lekang, (2007) an aquaculture farm's technical components can be separated as follow:

- Production Units
- Water treatment and transfer units
- And additional equipment for monitoring, feeding and handling fish.

An aquaponics system has similar components to that of aquaculture systems but recirculating water and including a hydroponic grow component calls for a design which facilitates both aquaculture and hydroponic needs. This is illustrated by Rakocy, et al. (2006), the essential elements of an aquaponic system are (see figure 3.4):

- Fish rearing tank
- Solid waste removal component
- Biofiltration component
- Hydroponic component
- Sump or water holding component.

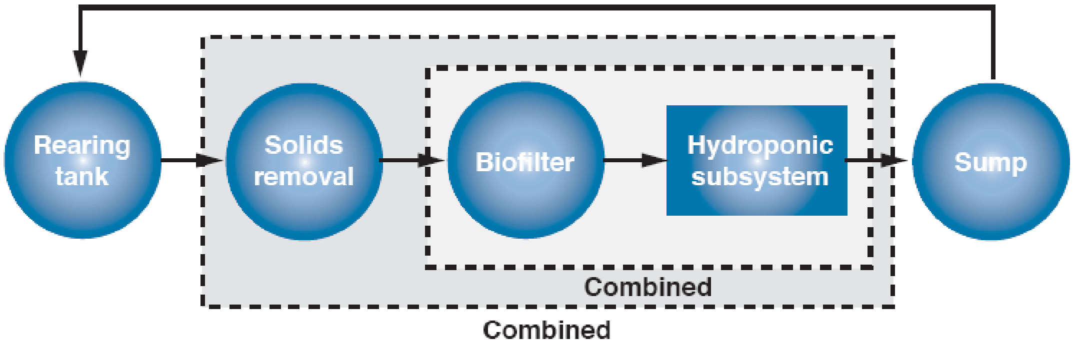

Figure 3.4: Components of an aquaponic system (Rakocy et. **al., 2006)**

Water temperature

The water temperature is the first aspect to consider determining which fish species you can farm with. Freshwater fish is classified into 3 thermal groups namely:

- Cold-water species: (4-18°C)
- Warm-water species: (4-25°C)
- Tropical-water species: (25-35°C)

A farmer should know what temperature characteristics his fish has and should keep the water at optimal levels to maintain good FCR and healthy fish. As illustrated in figure 3.5 it show that if fish are exposed to water temperature outside its preferred range its growth will decline and it will eventually die.

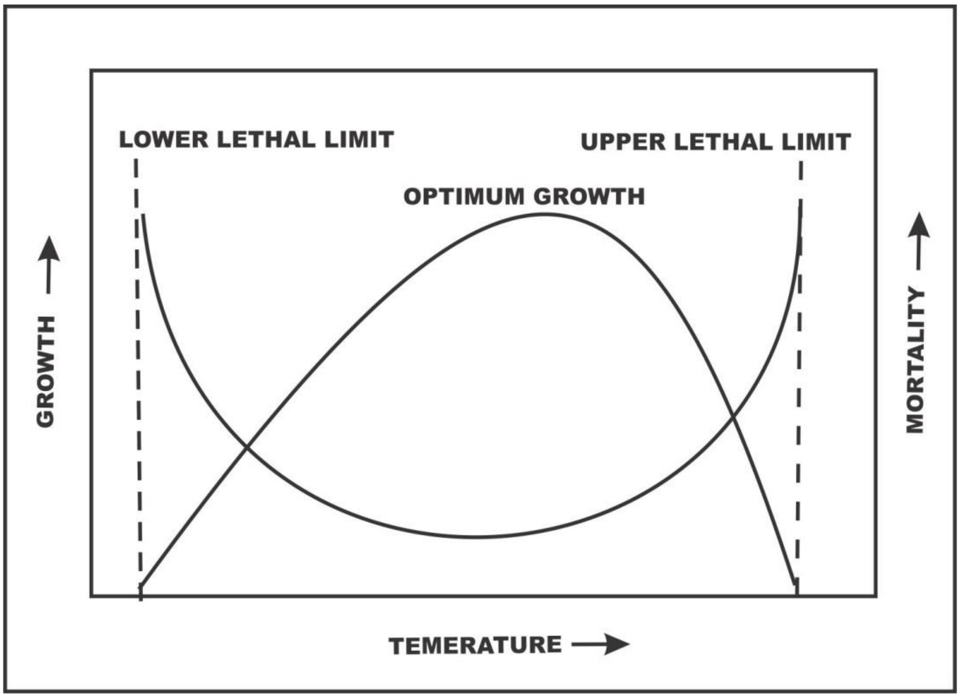

Figure 3.5: The relationship between fish growth and temperature (Salie 2011)

Aquaculture Tanks

Aquaculture tank characteristics should be based on effective water exchange, cost efficiency, self-cleaning ability, durability, and have a smooth surface (Aquaculture Division, 2007).

Water that enters the tank should flow the longest possible route before it exits the tank as to provide efficient water exchange. Dead zones are areas in water tanks which are not exchanged with new water; this creates anaerobic waste accumulation zones which is a risk to the well-being of the fish as well as fish will not swim in those areas thus reducing the operational size of the tank (Aquaculture Division, 2007; Lekang, 2007)

It is recommended to have tanks which have no dead zones to maximize efficiency and enable it to clean itself (see figure 3.6). The water inlets should also be located and orientated to enable a circular flow.

Circular tanks provide the most efficient use of construction material as pressure is equally spread among the circumference of the tank which requires thinner walls (Lekang, 2007). It is also self-cleaning and distributes water throughout the entire tank.

Tanks do not necessarily require sloped bottoms to drain efficiently; if the right water flow is managed the tank will clean itself. The hydraulic force has a greater force in solid particles than what gravity does (Lekang, 2007).

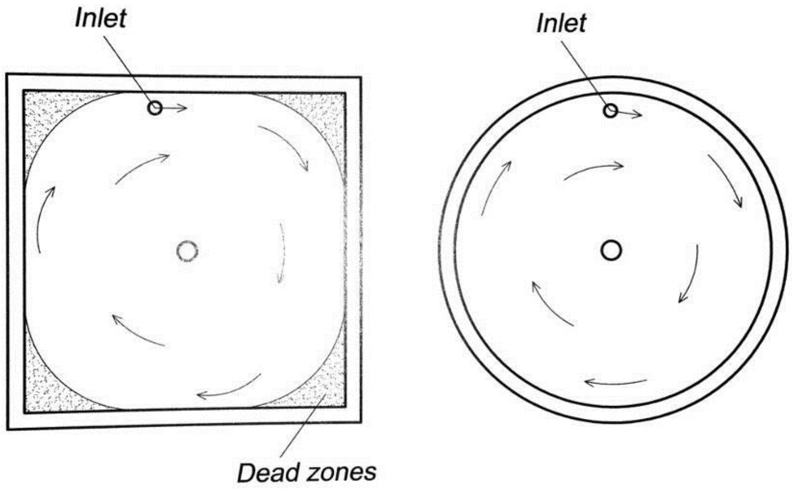

Figure 3.6: Water circulation in a square and circular tank (Lekang, 2007)**.**

Correct design for water outlets is important for efficient self-cleaning and water exchange. Using a central standpipe 'tower outlet' as water outlet and designing it to be able to shock drain a fish tank would be beneficial to clean the tank of settled solids that are difficult to remove by normal hydraulic flow (Lekang, 2007). The shock drain principle works by dropping the pipe externally that controls the water level see figure 3.7 below. Outflow pipes should have as little as possible bends and elbows and should enable solids to be removed without breaking them up through turbulence.

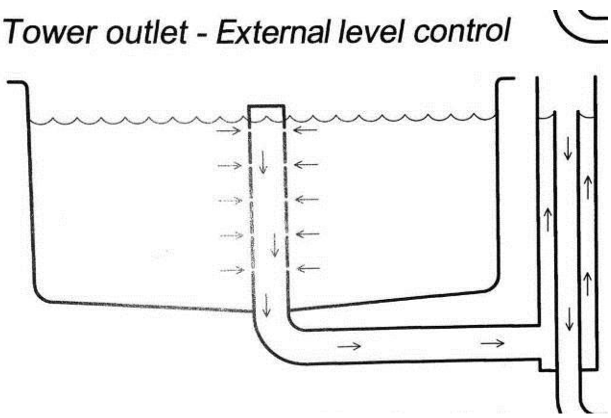

Figure 3.7: Side view of water tanks illustrating external level control draining (Lekang, 2007:170)

Waste Separators

The accumulation of organic and inorganic matter from aquaculture farms is a normal waste product which should be managed to prevent environmental degradation. Aquaculture farms have several methods namely: Mechanical or membrane filtration.
The system I am reviewing at WAF uses a mechanical filtration system, although recognizing other systems; for the purpose of this study I will only discuss mechanical filtration here.

Waste separation is done differently according to the type and size aquaculture system you have. The basic gravitational separators that are used are:

- Colonization dams or settling basins, which are used in dams and large aquaculture farms;
- Integrated treatment systems such as artificial wetlands;
- Swirl separators and Hydrocyclones, which are induced gravitational colonization systems (see figure 3.8 below).

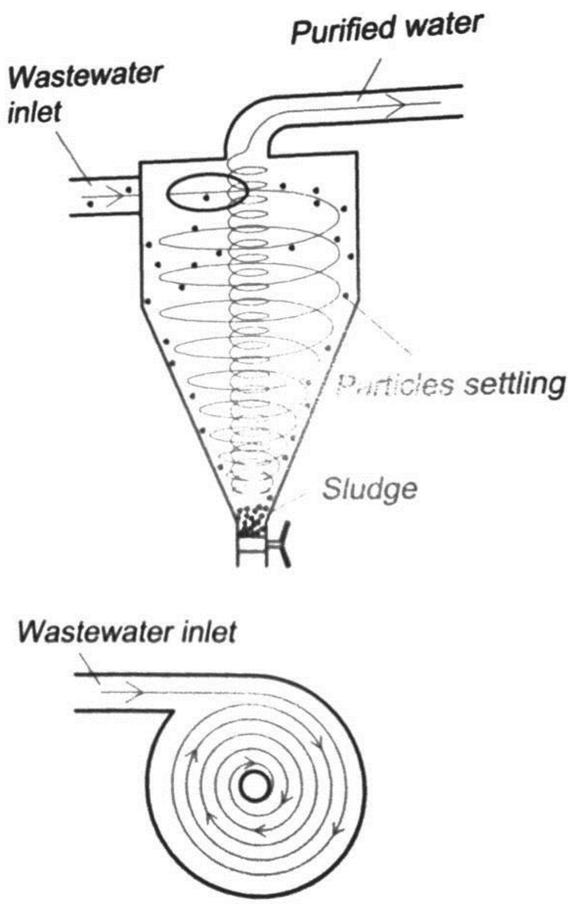

Figure 3.8: Hydroclone- swirl separator (Lekang, 2007)

A swirl separator or hydrocyclone enables particles which are denser than water to fall and collect at the bottom of the tank, the centrifugal force presses down in addition to increase the downward pressure of the particles. The swirl separators are simple in design and are generally self-cleaning; the disadvantage is that this system requires uniform water flow to achieve optimum efficiency (Lekang, 2007).

Aeration

In aquaculture oxygen plays an important role in the production of fish but it is important to understand that its availability as dissolved oxygen is a function of temperature, in which cooler temperature have higher dissolved oxygen

Dissolved oxygen should be measured 3 times a day and be recorded for record keeping and measurement.

The amount of dissolved oxygen is determined by;

- Water temperature;
- Volume and quality of water;
- Fish activity;
- Fish size (Salie, 2011).

When water quality is deprived of dissolved oxygen fish will demonstrate unusual behaviour such as:

- Increased ventilation and gasping for air at the water surface;
- Loss of appetite;
- Passive behaviour;
- Colour change.

A constant supply of dissolved oxygen is important in intensive aquaculture systems. Open dam extensive systems are supplied by diffused oxygen and phytoplankton and do not require additional oxygen input unless the stocking density is very high.

Oxygen can be supplied by:

- Diffused air aerators (air pump, see figure 3.9), such as compressors and blowers;
- Paddle wheel aerators;
- Vertical pump aerators;
- Propeller – aspirator pump aerators;

- Pump spray aerators;

WAF used diffused air aerators both compressors and blowers as the fish containers were small and compact. Other aeration options were not viable because they were too big.

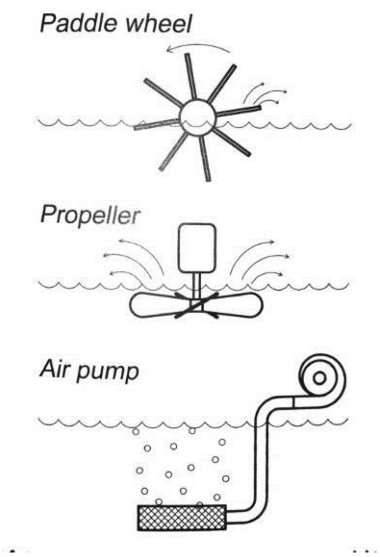

Figure 3.9: Paddle wheel, propeller and air pump aeration methods (Lekang, 2007)**.**

Plumbing

The veins that keep an aquaculture system running are its water transport network. Every aquaculture system requires water to be transported at different rates depending on the size of the system, the fish species and the design. It is important to understand basic principles of hydrodynamics and how to repair systems should a leak or pipe break. Correct design is very important to avoid unnecessary costs and possible fish losses on a later stage.

Water can be transported through channels or pipes. Channels are open non pressurized transport and pipes can flow constantly under pressure. Channels provide simplicity as the flow can be easily managed and visually monitored. The disadvantages are that channels require a constant slope to transport water. Pipes provide efficient and accurate water transport and are usually made from weld able polyethylene or glue able polyvinyl chloride; PVC. It is important to use standardized pipes to ease maintenance and to create simplicity (Lekang, 2007).

It is important to use large enough pipe diameters and have minimal bends to avoid water hammer (the rush and sudden pressure surge in pipes when water have to stop or change direction) and clogging nutrient build up. Water inlet and outlet levels and velocities should be able to be controlled at all times to allow for maintenance, proper flow rate and balance (Aquaculture Division, 2007)

Pipes should have valves between each section to enable the isolation of certain elements of the system for repairs or containment. A union joint (joint between pipes by means of a union) is recommended as it is easy to separate in case a system needs to be repaired or dis assembled.

Biofiltration

The difference between biological, chemical and mechanical filtration is that with biological filtration the toxic substances in the water neutralized naturally whereby the chemical and mechanical filtration physically removes the substances. Biological filtration or biofilters is very effective in dealing with nitrogenous waste compounds like ammonia produced by bacteria which feeds on uneaten feed, dead fish and faeces as well as by fish which excretes ammonia during respiration which is toxic (Salie, 2011).

The biofilter consists of beneficial bacterial growth which breaks down ammonia to nitrate. The bacteria originates at the surface of the biofilter and with the help of aeration (aerobic conditions) will spread to the media layers which is placed I the biofilter to enhance bacterial growth. The biofilter is considered as being the most difficult device to manage in RAS systems (Badiola, Mendiola & Bostock, 2012).

Ammonia is broken down in three phases:

1. Firstly is ammonia is broken down by protonation to an ammonium ion with the help of water flow;
2. Secondly the nitrosomonas bacteria breaks down and transforms ammonium into nitrite;
3. Thirdly the nitrobacter bacteria transform the nitrite into nitrate (see figures 2.13 and 3.10 for illustration).

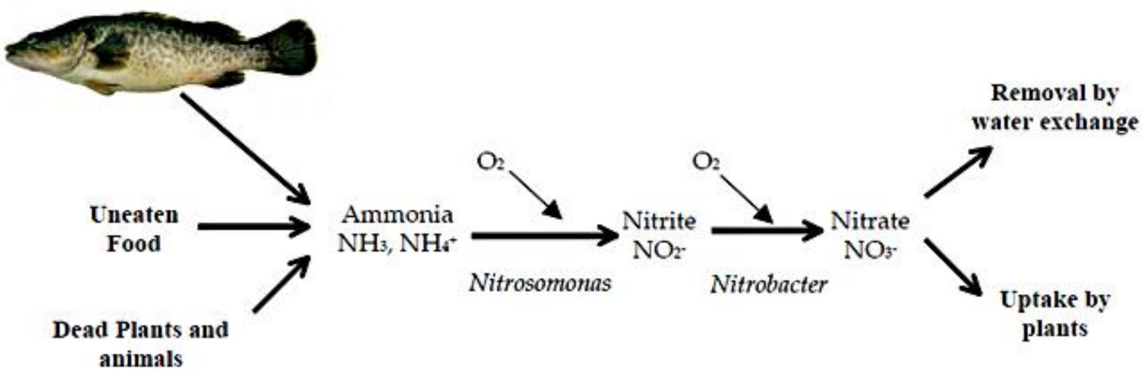

Figure 3.10: Illustration demonstrating the nitrification process in biofilters (Victoria, 2005)**.**

Untreated aquaculture waste water could cause serious environmental damage to aquatic life; it can be treated through simple biofiltration which can be viewed as the link between an aquaculture and hydroponics. The broken down nutrients of aquaculture waste water serves as essential nutrients for plant growth. This eliminated the need and additional input of chemical fertilizers in hydroponics (Childress, 2002).

3.5 Hydroponic Greenhouse Production

3.5.1 Nutrient Solution Management

According to Rakocy et al. (2006) & Kempen (2012) plants do not need soil to grow as it was merely a support structure, plants require only 16 essential nutrients (including C,O,H) which can be put into three categories:

- Essential macronutrients: Carbon (C), Oxygen (O) and hydrogen (H), these are supplied by water (H_2O) and carbon dioxide (CO_2) in the air.
- Primary macronutrients: Nitrogen (N), Phosphorous (P), Potassium (K), Sulphur (S), Magnesium (Mg) and Calcium (Ca), these nutrients are supplied in large quantities.
- Micronutrients: Iron (Fe), manganese (Mn), sink (Zn), chlorine (Cl), Molybdenum (Mo), Boron (B), and Copper (Cu), micronutrients are supplied in very small amounts.

The 16 essential nutrients must be applied according to the specific plant's requirements and be balanced to enable plants to grow to its optimum genetic ability. Each of the nutrients has specific characteristics and functions to produce crops which are strong, healthy, tasty and large. See table 3.1 below for high quality irrigation water.

Nutrient deficiencies or excesses can be measured with scientific measuring equipment or it can be visually monitored. Nutrients are measured as total dissolved solids (TDS) or in ionized form through electrical conductivity (EC). The major ions that are used to transport nutrients are: NH4+, K+, Mg++, Ca++ which are the positively charged cations and NO3-, H2PO4-, SO4--, which are the negatively charged anions. Together cations and anions should be a balanced total which represent the EC (see table 3.2 and 3.3)(Rakocy, et al., 2006).

. The water nutrient levels can be determined by taking samples and testing the EC and pH of the water further running a laboratory test to determine the nutrient levels and nutrient deficiencies. Afterwards a nutrient solution can be prepared using the Steiner or Hoagland method/ratio to match the required nutrient levels for the specific crop. For aquaponic systems the nutrient mix would be a weak solution as it is recirculating the nutrients in a closed system, therefore refer to the ratios of table 3.2 and 3.3 (Kempen, 2012). To an experienced eye nutrient deficiencies can be determined by examining leaves and fruits of plants.

Macronutrients like K+, and Ca++ is usually insufficient in aquaponic systems and should be manually supplied because the biofilters' nitrification increases acidity in the water, it is recommended to supplement K+ as potassium hydroxide (KOH) and calcium as calcium hydroxide (Ca(OH)2) which is both basic compounds which neutralizes the acid build up.

Micronutrients are available to plants as Fe^{+2}, Mn^{+2}, Cu^{+2},B^{+3} and Mo^{+6}. Nutrients such as Fe^{+2} are insufficient in aquaponic systems and require to be supplemented generally as chelated Fe^{+2}. A Fe^{+2} foliar leaf spay could also be used to apply supplemented iron (Rakocy, et al., 2006). Generally the point is to enable the plants to extract as much nutrients form the irrigation water as possible. The EC of drainage in system should not be more than 50% of the original supplied nutrient content, otherwise nutrients are wasted (Kempen, 2014).

Characteristics of High-Quality Irrigation Water

Characteristics	Desired Level	Upper Limit
Soluble Salts (EC)	0.2 to 0.5 µS/cm	0.75 µS/cm for plugs; 1.5 µS/cm for general production
Soluble Salts (total dissolved solids)	128 to 320 ppm	480 ppm for plugs; 960 ppm for general production
pH	5.4 to 6.8	7
Alkalinity ($CaCO_3$ equivalent)	40 to 65 ppm (0.8 to 1.3 meq/L)	150 ppm (3 meq/L)
Bicarbonates	40 to 65ppm (0.70 to 1.1 meq/L)	122ppm (2 meq/L)
Hardness ($CACO_3$ equivalent)	<100 ppm (2 meq/L)	150 ppm (3 meq/L)
Sodium (Na)	<50 ppm (2 meq/L)	69 ppm (3 meq/L)
Chloride (Cl)	<71 ppm (2 meq/L)	108 ppm (3 meq/L)
SAR (Sodium Absorption Ratio)	<4	8
Nitrogen (N)	<5 ppm (0.36 meq/L)	10 ppm (0.72 meq/L)
Nitrate (NO_3)	<5 ppm (0.08 meq/L)	10 ppm (0.16 meq/L)
Ammonium (NH_4)	<5 ppm (0.28 meq/L)	10 ppm (0.56 meq/L)
Prosperous (P)	<1 ppm (0.3 meq/L)	5 ppm (1.5 meq/L)
Phosphate ($H2PO_4$)	<1 ppm (0.01 meq/L)	5 ppm (0.05 meq/L)
Potassium (K)	<10 ppm (0.26 meq/L)	20 ppm (0.52meq/L)
Calcium (Ca)	<60 ppm (3 meq/L)	120 ppm (6 meq/L)
Sulphate (SO_4)	<30 ppm (0.63 meq/L)	45 ppm (0.94 meq/L)
Magnesium (Mg)	<5ppm (0.42 meq/L)	24 ppm (2 meq/L)
Manganese (Mn)	<1 ppm	2 ppm
Iron (Fe)	<1 ppm	5 ppm
Boron (B)	<0.3 ppm	0.5 ppm
Copper (Cu)	<0.1 ppm	0.2 ppm
Zinc (Zn)	<2 ppm	5 ppm
Aluminium (Al)	<2 ppm	5 ppm
Fluoride (F)	<1 ppm	1 ppm

Table 3.1: Characteristics of High quality irrigation water (Whipker, Dole, Gavins, & Gobson, 2003; Kempen, 2012)

Electrical Conductivity (EC)

The EC of a water solution is an indicator of the mineral/salt content. Charged particles in the solution enable conductivity. The higher the EC measurement means there is an increased amount of charged ions/ salt content. The standard nutrient solutions require EC values to be maintained between 1.5 – 2.5 (Kempen, 2014). It recommended that the EC levels are managed according to the specific crop's requirement (see table 3.2 below for recommended EC levels for specific crops).

	Macronutrients ($mmol_c.L^{-1}$)							EC^x ($mS.cm^{-1}$)	Micronutrients ($mg.L^{-1}$)					
	NH_4	K	Ca	Mg	NO_3	H_2PO_4	SO_4		Fe	Mn	Zn	B	Cu	Mo
Disa	1.7	1.9	1.4	1.0	3.3	0.7	2.0	**0.60**	0.45	0.55	0.25	0.20	0.03	0.04
Cymbidiium	1.0	2.8	2.0	1.5	4.0	0.8	2.5	**0.73**	0.45	0.55	0.25	0.20	0.03	0.04
Anthurium	0.3	3.8	2.5	1.9	6.1	0.8	1.6	**0.85**	0.85	0.15	0.25	0.30	0.04	0.05
Lettuce	0.7	5.5	5.8	1.0	10.0	1.0	2.0	**1.30**	1.00	0.55	0.25	0.30	0.05	0.05
Rose	0.7	4.3	6.5	2.5	10.4	1.1	2.5	z **1.40**	0.85	0.30	0.25	0.20	0.03	0.05
Gerbera	1.5	5.5	6.0	2.0	11.0	1.2	2.8	**1.50**	2.00	0.30	0.25	0.30	0.05	0.05
Gypsphila	0.7	4.0	7.3	3.0	12.0	1.0	2.0	**1.50**	0.85	0.55	0.25	0.30	0.05	0.05
Strawberry	1.0	5.0	6.5	2.5	10.0	1.0	3.0	**1.50**	1.15	0.75	0.45	0.10	0.05	0.05
Alstromeria	0.7	5.0	7.0	2.5	10.5	1.0	3.7	**1.52**	1.40	0.30	0.25	0.30	0.05	0.05
Amaryllis	1.2	6.3	6.0	2.0	12.0	1.0	2.5	**1.55**	0.55	0.55	0.30	0.30	0.04	0.05
Beans	1.0	5.5	7.0	2.5	12.0	1.0	3.0	**1.60**	0.85	0.30	0.25	0.20	0.03	0.05
Carnation	1.0	6.0	7.0	2.0	12.3	1.2	2.5	**1.60**	1.40	0.55	0.26	0.33	0.05	0.05
Crysanth	1.0	6.0	7.0	2.0	12.3	1.2	2.5	**1.60**	1.40	0.55	0.26	0.25	0.05	0.05
Brinjal	1.0	4.5	7.0	4.0	12.5	1.0	3.0	**1.65**	0.85	0.55	0.30	0.38	0.05	0.05
Courgette	1.0	5.5	7.0	3.0	13.0	1.0	2.5	z **1.65**	0.85	0.55	0.30	0.38	0.07	0.05
Cucumber	1.0	5.5	7.5	2.5	13.0	1.0	2.5	z **1.65**	0.85	0.55	0.30	0.30	0.05	0.05
Pepper	0.3	5.2	9.0	3.5	12.8	1.2	4.0	**1.80**	0.85	0.55	0.30	0.30	0.05	0.05
Tomato	1.0	7.0	8.5	3.5	12.5	1.5	6.0	y **2.00**	0.85	0.55	0.30	0.30	0.05	0.05
Melon	1.2	7.0	9.8	4.0	13.0	1.5	7.5	y **2.20**	0.85	0.55	0.25	0.35	0.05	0.05
Cherry toms	1.5	8.0	9.5	4.0	13.0	1.5	8.5	y **2.30**	0.85	0.55	0.30	0.30	0.05	0.05
Swiss chard	1.0	7.0	10.8	4.2	13.0	1.5	8.5	y **2.30**	0.85	0.55	0.25	0.35	0.05	0.05
Amaranthus	1.0	7.0	10.8	4.2	13.0	1.5	8.5	y **2.30**	0.85	0.55	0.25	0.35	0.05	0.05

Table 3.2: Nutrient solutions for crops grown in open drain to waste systems (Kempen, 2014)**.**

	Macronutrients (mmol$_c$.L^{-1})							EC* (mS.cm^{-1})	Micronutrients (mg.L^{-1})					
	NH_4	K	Ca	Mg	NO_3	H_2PO_4	SO_4		Fe	Mn	Zn	B	Cu	Mo
Disa	1.7	1.9	1.4	1.0	3.3	0.7	2.0	**0.60**	0.45	0.55	0.25	0.20	0.03	0.04
Cymbidiium	1.0	2.8	2.0	1.5	4.0	0.8	2.5	**0.73**	0.45	0.55	0.25	0.20	0.03	0.04
Anthurium	0.3	3.4	1.8	1.3	4.5	0.8	1.5	**0.68**	0.85	0.15	0.25	0.20	0.03	0.05
Lettuce	0.6	3.9	3.8	0.6	7.0	0.8	1.1	**0.89**	1.00	0.55	0.25	0.30	0.05	0.05
Rose	0.6	2.2	1.7	1.0	4.0	0.5	1.0	**0.55**	0.51	0.30	0.22	0.20	0.02	0.03
Gerbera	0.8	4.5	3.1	0.8	7.0	0.6	1.6	**0.92**	1.42	0.30	0.19	0.20	0.03	0.05
Gypsphila	0.7	3.4	5.2	2.0	9.0	0.8	1.5	**1.13**	0.85	0.30	1.90	0.30	0.05	0.05
Strawberry	0.8	3.6	3.2	1.3	6.1	0.8	2.0	**0.89**	1.00	0.75	0.40	0.08	0.05	0.05
Alstromeria	0.7	4.3	3.4	1.4	6.8	0.7	2.3	**0.98**	1.40	0.30	0.25	0.20	0.05	0.05
Amaryllis	0.5	3.6	2.5	1.2	6.0	0.5	1.3	**0.78**	0.55	0.40	0.30	0.20	0.03	0.05
Beans	1.0	4.7	4.3	1.5	9.4	0.7	1.4	**1.15**	0.57	0.30	0.19	0.20	0.03	0.05
Carnation	0.8	3.9	3.1	1.2	6.9	0.7	1.4	**0.90**	1.12	0.28	0.20	0.22	0.03	0.05
Crysanth	0.8	3.9	3.1	1.2	6.9	0.7	1.4	**0.90**	1.12	0.28	0.20	0.15	0.03	0.05
Brinjal	0.7	4.4	5.1	2.4	9.5	0.8	2.3	**1.26**	0.85	0.55	0.30	0.38	0.05	0.05
Courgette	0.8	4.0	3.6	1.9	7.8	0.7	1.8	**1.03**	0.57	0.55	0.30	0.33	0.07	0.05
Cucumber	0.8	4.5	5.3	1.8	9.6	1.0	1.8	**1.24**	0.85	0.55	0.30	0.30	0.05	0.05
Pepper	0.3	4.4	6.2	2.5	10.4	1.0	2.0	**1.34**	0.85	0.55	0.24	0.25	0.05	0.05
Tomato	0.8	4.8	4.3	2.2	8.3	1.2	2.6	**1.21**	0.85	0.55	0.24	0.20	0.05	0.05
Melon	1.0	4.7	5.8	2.3	8.6	1.2	4.0	**1.38**	0.70	0.55	0.25	0.30	0.05	0.05
Cherry tomato	1.1	5.4	4.8	2.5	8.7	1.2	3.9	**1.38**	0.85	0.55	0.24	0.20	0.05	0.05
Swiss chard	0.8	5.0	6.0	2.0	7.0	1.0	5.8	**1.38**	0.85	0.40	0.20	0.30	0.05	0.05
Amaranthus	0.8	5.0	6.0	2.0	7.0	1.0	5.8	**1.38**	0.85	0.40	0.20	0.30	0.05	0.05

* Electrical conductivity with nutients dissolved in distilled water

Table 3.3: Nutrient solutions for crops grown in closed systems (Kempen, 2012)

Aquaponic systems will generally require lower EC levels because nutrients are constantly recycled and produced by fish (see comparison between two nutrient tables 3.2 and 3.3). EC levels between 0.3 – 0.6 will produce good results (Rakocy, et al., 2006).

If EC levels build up over 3.5 in a hydroponic system the water should be flushed, more plants should be planted or if using an aquaponic system – fish stocking density should be reduced.

Acidity and Alkalinity of water (pH)

The pH is a figure that expresses the acidity and alkalinity of a water solution. It is very important for a farmer to maintain a balanced pH in the water solution. According to Rakocy et al.(2006), Maboko, Plooy & Brown, (2007) and Kempen (2012) hydroponic nutrient solution should be kept between 5.8-6.5 for optimum growth and nutrient uptake. When pH levels are below the recommended levels nutrients like calcium, phosphorous, molybdenum sharply decrease. When water become too alkaline above the recommended levels trace metals such as copper, zinc, iron and manganese will be less available as it will be less soluble in water and precipitate to the water surface (Rakocy, et al., 2006).

Recirculation of Nutrients

In normal drain to waste (non-recirculating) hydroponic systems an average of 40% of nutrients are leached out because plants don't always use the maximum amount available (Kempen, 2012). Not only is this a waste of valuable nutrients it also causes environmental damage in ecosystems as nature cannot handle the excess nutrients available.

A solution is to recycle nutrients through recirculation which can be done by installing a sump dam or tank for containment (see figures 3.4, 0.11 and 0.12 for illustration). The water can thus be monitored adjusted and be reused. The only challenges to this are that it is:

- Cheaper and easier not to recirculate, in terms of equipment costs and management;
- There is no policy forcing South African farmers to recirculate nutrients,
- The composition of the recycled water is not the same as the original supply which is provides unwanted results and can cause yields to be lower.
- Management is difficult and expensive as the water requires to be monitored with specialized equipment and analysis (Kempen, 2014).

Dissolved Oxygen (DO)

Dissolved oxygen is required in the root zone of plants in order for plants to respire and assist with nutrient uptake and transport. If DO is insufficient it would cause cell breakdown in roots, what is otherwise referred to as root rot (Rakocy, et al., 2006).

3.5.2 Climate Control

Climate control is the main function behind controlled environmental farming. Although initially a big capital investment, it enables a farmer to avoid the limiting factors associated by seasonal change and climatic conditions.

The reason for choosing climate control should be justified purely by cost efficiency and functionality. To decide on the appropriate cost effective structure requires a farmer to have scientific information and data of crop characteristics and requirements. The local climate conditions should also be well known to design the right structure that addresses the environmental shortcomings or threats.

- Firstly a farmer needs to identify the correct controlled climate structure. It is important to identify where to grow, which crop to select, for what market to grow and in what time frame will be farmed.
- Secondly a farmer needs to know what the local limiting climatic factors are: light, temperature, humidity, carbon dioxide (CO_2) or wind.

A farmer should be well accustomed to the locality of the project because it determines the feasibility of climate controlled structure farming. Geographic locality features the prospective farmer should have knowledge of are:

- The market for your product and easy access to the market;
- The freshwater quality and supply;
- Wind (on exposed areas) and frost (low lying areas);
- Access to the northern slope for maximum sunlight exposure;

Only poor climatic conditions and high value products justify expensive high technology climate control structures (Kempen, 2014).

Light

The solar radiation spectrum directly determines plant growth and productivity (Gaudreau et al., 1994). It has specific effects on different plant responses such as photosynthesis, phototropism, and photomorphogenesis (Hogewoning et al., 2010). Plants classify light quality according to different wavelengths. The most important wavelengths are the blue, red, far red and infra-red light spectrum (Kempen, 2014). This controls the most important functions in plants like node lengths, root development, vegetative growth and colour.

The choice of lighting equipment is directly a factor of economic justification. Artificial lighting can be expensive but can lead to improved crop production. Traditionally fluorescent lights have been used which are energy efficient and produce similar light spectrum as the sun but not as high intensity.

The most popular lights that are used are:

- LED lights, because they are increasingly more affordable, they have a long lifespan, they don’t produce heat, they can be controlled as to produce different light spectrums and wavelengths and they are energy efficient (Kempen, 2014).

Relative humidity

An ideal humidity level in greenhouses are considered to be between 60-75% (Kempen, 2014). Managing humidity in controlled climate structures allows the ability to manipulate irrigation, nutrient uptake and productivity of plants.

Low relative humidity levels causes plants to increase transpiration which in effect causes water stress in plants and a decreased photosynthetic productivity. Low relative humidity levels also causes increased water transport to fruit and lower nutrients like K, Ca, and Mg in plants causing physiological and taste disorders (Chiloane, 2012; TNAU, 2013).

A high relative humidity causes a reduced water transpiration and nutrient uptake in plants. This may lead to nutrient deficiencies like plants that have:

- Light coloured leaves;
- Soft leaves;
- Weak growing points;

This mainly causes plants to have a lower shelf life and that condensation takes place in the greenhouse/tunnel which is prone to develop pathogens and disease (Kempen, 2014).

Temperature control

Controlled climate structures like greenhouses and tunnels should create an ideal environment for specific crops to grow. Although plants have different requirements, it is recommended that temperature of crops be:

- 25-28°C on leaf surface temperature;
- 18-28°C roots zone temperature (Rakocy, et al., 2006; Kempen, 2014).

In warm seasons heat should be controlled and prevent a build-up in the structure.
Heat can be removed through:

- Natural ventilation; passive ventilation in greenhouse structures.
- Evaporative cooling; methods such as using wet walls and misters in greenhouses to raise relative humidity levels and cool down the temperature. Alternative measures are to lower the humidity levels by venting the air with fans or roof top openings, this causes plants to transpire and cool down the air temperature.
- Mechanical cooling.

Alternatively preventative measures can be used to avoid heat build-up. Methods that are used work on reflecting and reducing heat build-up. To reflect heat farmers use screens such as white plastic or aluminium foil netting. Other netting such as shade or calcium hydroxide paint reduces the amount of light entering the greenhouse. The netting also helps by diffusing light in the greenhouse to approach the plants' leaves from different angles (Kempen, 2014).

In colder months greenhouses should plant crops that are in season and can withstand the cold or if it's a high value crop and the additional cost is justified the greenhouse should be heated.

Heating a greenhouse is firstly done through prevention measures:

- To prevent air leaks such are open roofs, doors or other gaps;
- To prevent heat escaping through conductive losses in other words as to minimize roof area and to insulate or remove thermal bridges such as metal parts. This has to be addressed and avoided before a greenhouse structure is built.
- Other ways of prevention is to capture infrared radiation by installing specialized netting and roof covers to trap infrared in the greenhouse which will heat the interior of the greenhouse,

Direct heating can be done with air heaters, burners or solar heaters channelling water in pipes between leaves.

Carbon Dioxide

It is little known that carbon dioxide has a greener side to it. For plants thrive under high CO_2 levels as it is plant food and greenhouses all over the world are realizing the benefits of CO_2 supplementation (Stafford, 2007).

CO_2 is a limiting factor to plant photosynthesis, which means if the CO_2 levels are increased the photosynthetic rate will also increase leading to faster growth (Kempen, 2012).

Our atmospheric CO_2 levels have increased from 270ppm to about 360 ppm since preindustrial times (Schippers et al., 2004). Plants and microscopic algae can help reduce atmospheric CO_2 levels especially in urban areas which have higher CO_2 levels.

Greenhouses needs to be constantly vented to allow adequate supply of atmospheric CO_2 are present. In unventilated greenhouses, enriching the air with CO_2 gas to double the atmospheric levels or even more can increase leafy plant production between 30-50% (Schippers et al., 2004; Rakocy, et al., 2006; Kempen, 2014).

Installing and using CO_2 burners or supply can be expensive and using decomposing material could pose pathogen risks. Methods of integrating alternative CO_2 supplies like aquaculture systems to greenhouses may prove effective because according to Rakocy et al. & Salie (2006;

2011), CO_2 is constantly vented form fish culture water which needs to be removed as it causes toxicity to fish and has an impact on pH and ammonia in water.

3.5.3 Structures

Crop climate control structures are the infrastructure that enables farmers to protect plants from adverse weather effects and to artificially manipulate and control optimum conditions for crop growth.

Crop production structures are divided into greenhouses and tunnels. There are many options to choose from which all have unique features. The decision should be based on price and the right features like providing the optimum growing conditions for a specific crop at the most cost effective price (Kempen, 2014).

Tunnel structures are good for non-trellising crops and lower value crops as it is simple structures. Tunnel structures have some slight variations as some like the Haygrove and Spanish tunnels can lift up and down which provide good protection against the elements. It is important to align these open structures with the predominant wind conditions. Greenhouses and tunnels should normally be aligned on its length to face north to get an equal amount of sunlight on all plants.

Greenhouses
Greenhouses are generally more expensive and are rugged and strong able to withstand high wind speeds and is made for higher value crops and crops which requires trellising. Greenhouses come in various designs required for different climates. Greenhouses can be designed to enable roof opening to release heat in very hot climates and can also be covered with more specialized roof covers like polycarbonate.

Roof covers
Roof covers are there to enable optimum growing conditions through which sunlight can penetrate the plants to enable them to photosynthesize and grow. Roof cover choice is based on cost and functionality.

General roof cover types are:

- Plastic; which are economical but effectively lasts only two years, after two years the light transmittance is decrease which has an effect on plant growth. Some plastic has some special features like anti-drip, anti-dust, anti-UV and far-red limiting properties.
- Polycarbonate; expensive but lasts up to 10 years and are strong, light and durable with a 90% light transmittance.
- Netting; although simple and cheap, netting is useful to lower light intensity during warmer months and protects against frost, wind and humidity.
- Glass; glass maintains uniform state and has a high light transmittance of 93% but it has some limiting effects on UV transmittance which causes glasshouse disease in plants which required UV light.

3.5.4 Growing Methods

Growing medium substrates

Media based growing systems work very well and are easy to use, it is most popular with hobbyists and small producers (Storey, 2014). It is also works very well with growing large structure plants.

Growing mediums are classified between organic and inorganic medium substrates. Inorganic grow mediums are usually sterilized and easy to control, this include:

- Vermiculite, which has a high porosity but is not very stable;
- Sand, which is cheap but have a low porosity;
- Perlite, which is permeable and stable;
- Rock wool which is light and permeable but is environmentally unfriendly;
- LECA; however expensive with a high embedded energy it is light weight, has a high permeability and long life span

Organic growing mediums are generally cheaper but are not naturally sterilized, these include:

- Wood chips, which is fairly abundant and cheap;
- Peat which has a high water holding capacity but is non-renewable;
- Coir, which is cheap and stable.

The main disadvantages of organic medium are that their lifetime is shorter compared to inorganic mediums.

Solution Culture Methods
Solution culture methods do not use any solid substrate medium for root support, only structural support and a nutrient solution. Solution culture methods are more popular and commercially feasible for larger producers (Storey, 2014). According to Rakocy et al. (2006) & Kempen (2012) examples of solution culture methods that are often being used in closed systems are:

- Drip systems, dripping systems constantly drip nutrient solution onto the medium like wood chip substrate;
- Aeroponics, functions by using fine sprayers to spray the root zone with the nutrient solution. The root zone and plant area is usually separated by a cover;
- Nutrient film technique[10] (NFT), a method that functions through pumping nutrient solution through a horizontal pipe, plants are inserted on the top of the pipes so that the root medium gets contact with the nutrients as well as being aerated;
- Gravel flow technique (GFT), a method similar to ebb and flood systems using gravel.
- Deep water culture or raft systems are very popular commercial techniques which functions as a solid polystyrene raft which floats on aerated nutrient solution water, good for tropical and southern hemisphere areas and good for maintaining a constant root zone temperatures;
- Ebb and flood systems, these systems works on the flood and drain principle in which a container with substrate media is flooded and allowed to drain. When draining it allows for aeration in the root zone.
- A capillary mat allows nutrient solutions to be drawn towards plants through a capillary force of the surface.
- Vertical culture methods, it is basically a combination of dripping and NFT systems.

3.5.5 Sanitation

The quality of irrigation water is very important in hydroponic systems because of the intensity and compactness of the system. Water quality should be regulated according to the needs of the plants. In recirculating systems which also applies for aquaculture, pathogens including fungi, nematodes and viruses can spread rapidly.

[10] NFT is a hydroponic technique wherein a very shallow stream of water containing all the dissolved nutrients required for plant growth is re-circulated past the bare roots of plants in a watertight gully, also known as channels.

Preventative methods are recommended such as a well aerated system, biological control, sterilization of equipment, hands and feet (Kempen, 2014).

It is recommended to use:

- Chlorine, in hydroponic systems only;
- Hydrogen peroxide (H_2O_2) in hydroponic systems only;
- UV sterilization tubes, energy efficient but require clear water;
- Ozone, very effective but expensive;
- Or filtration methods such as slow sand filters or membrane filters to physically remove particles.

In aquaponics one has to consider methods that acknowledge aquaculture principles; no chemical fungicides, herbicides or pesticides can be used as this will poison fish in the system. Chlorine should also be avoided as this would destroy beneficial bacteria in the biofilter.

3.5.6 Seedling Production

Growing and supplying your own seedlings is recommended to reduce costs of buying and transporting them as well as reducing the risk by introducing pathogens or fungi into your greenhouse.

Because controlled environment farming techniques such as hydroponics are well managed and have expensive capital inputs, seedling production should be optimised to produce high quality, healthy and homogenous seedlings. Several factors should be considered in growing seedlings (Kempen, 2012):

- Seeds should be sourced from a trusted source which produce good genetic properties;
- Seeds should be disease free;
- Seedling growing medium and containers should be free of pathogens thus sterilized. Sterilize a seedling container by dipping it in chlorine water or if chlorine is not available expose the containers to hot water (steam) for 30 seconds
- For germination seeds should be placed just beneath the soil and place the seedling container in a room with a high humidity of 85-95%. This can be done by blowing a heater fan over a bowl of water to covering the seedling tray with humid air.
- Seedling soil should be kept moist and compacted.
- Seeds should germinate well;

- Seedling trays should have a neutral pH;
- Seedling trays should be free of salt content (NaCl);
- Seedling trays should be placed lifted from the soil on two horizontal wires for automatic root pruning. Benefits are: roots that grow outside the container will dry out and die, and form new roots; no contact with soil that may carry pathogens, improved drainage, and compacted root medium is easier to handle.
- Maintain the seedling greenhouse conditions at: Air temperature- +-27°C, root zone temperature-+-19°C, and relative humidity levels at +-70%.
- Seedlings should be watered with a nutrient solution of 50% strength and continue to 100% when planting out.
- The seedlings root zone pH should remain between 5.5 and 6.5.
- Seedlings should be protected from fungal and viral infections through good biosecurity and control, preventing insects to enter the seedling room, keep relative humidity levels below 75%.

See photo 4.21 and the seedling production steps in section 4.8 which discusses steps followed during the experimental case study.

3.6 Ecological Approach to Aquaponic Management and Design

Section 2.3.7 mentioned the high water use efficiency per protein produced of aquaponics; further methods can be explored and incorporated into design and management of the systems. To improve the sustainability of aquaponic systems the following list of technical approaches can be integrated into system design and management. This section adds to the proposed approach to sustainably integrate aquaculture and hydroponic farming technologies and acts as a technical guideline for aspiring aquaponic farmers to increase the efficiency and sustainability of their projects.

Several basic environmentally friendly and energy efficient factors can be included in greenhouse design and management techniques:

- Building north facing, east-west orientated greenhouses with an asymmetric roof; enabling a greenhouse to face north (in southern hemisphere) without any shade throughout the year will enable the plants to produce at its optimum level,
- Insulating greenhouses well;

- Planting in season crops;
- Reducing greenhouse interior temperature through natural ventilation, reflection or capture in the form of solar collector panels (Tripanagnostopoulos, Y Siabekou & Tonui, 2007);
- Using energy efficient lighting and incorporate it with recycled “bottle lights”.
- Using passive cooling and heating ventilation methods (Korecko, Jirka, Sourek, Cerveny, 2010);
- Using black surfaces or surfaces with a high thermal mass will absorb heat and radiate it at night (Santamouris, Argiriou & Vallindras, 1994);
- Sinking the floor into the ground which diminishes heat loss and stores heat which can be radiated back at night (Korecko et al., 2010);
- Using earth to air heat exchangers to prevent overheating during summer and reduce energy consumption during winter (Santamouris, Argiriou, Vallindras, 1994);
- Using and reusing as much resources as possible, CO_2 gasses produced by the fish is an ideal use for plant supplementation;
- Treating fish diseases by simply adding a bit of salt in the water instead of chemicals and antibiotics (Rakocy, et al., 2006);
- Using biological control to manage pests in greenhouses (Kempen, 2014);
- Composting solid waste from fish to produce fertilizer for outdoor gardens;
- Using solar or biothermal energy to heat greenhouses and water, growing seasons can be extended by heating greenhouses or aquaculture with compost (see figure 3.11 below). According to Brown (2014) water can be heated up to 60°C by using compost. The CO_2 of compost can also be used to supply plants in greenhouses.

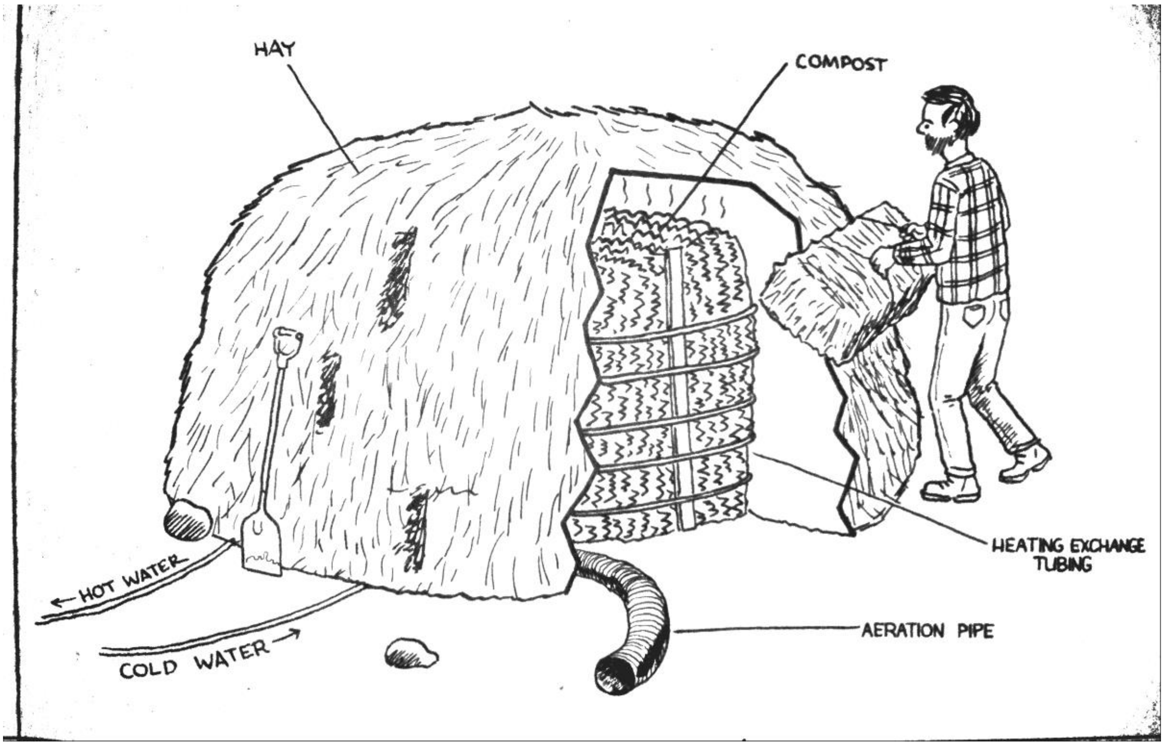

Figure 3.11: Compost powered water heater that can be incorporated with aquaponic systems

- Using cost effective structures made from recycled materials such as compacted tyres which acts as thermal mass (Reynolds, 1998);
- Using local labour and integrate local food markets, reducing the environmental footprint of the food and assisting local food security.

According to Lekang (2007) the primary function of aquaculture greenhouse or building are for environmental shelter. In South Africa the challenge is to keep the greenhouse cool in summer and warm in winter. Because operational costs so largely affects the feasibility of aquaculture and agriculture operations, looking at alternative methods such as earth sheltered walls, compost powered heat exchange and solar heating might be useful.

3.7 Factors to consider before beginning an operation

A list of 11 factors to consider before beginning an aquaponics project is derived from the 10th anniversary issue of the aquaponics journal (Rakocy, 2007):

1. Design calculations should be derived from the feeding rate ratio:
2. Keep feeding inputs constant;
3. Supplement the aquaponic nutrient solution with calcium, potassium and iron;
4. Ensure good aeration;
5. Clean system regularly by removing solids
6. Be careful that aggregate media don't clog areas or become anaerobic;
7. Use large pipes wherever possible;
8. Use biological control to manage pests;
9. Manage optimum biofiltration;
10. Manage required pH levels.
11. Use as less equipment and pumps as possible.

Table 3.4 gives a summary to the common feed-to-plant ratio's used in the literature.

James Rakocy	**Wilson Lennard**	**Jason Licamele**
60-100g Feed/ day for 1m2 growing surface	13-16 g Feed/ day for 1m2 growing surface	1kg Fish fed daily = 2.94kg Lettuce
	1kg fish feed/day supports 1500 lettuce plants	
	Assuming 30 plants/m2	

Table 3.4: Common Ratio's used in this study (Rakocy, et al., 2006; Licamele, 2009; Lennard, 2012)**.**

3.8 Conclusion

Due to the scientific nature of aquaculture and hydroponic greenhouse management and production it recommended to understand the theory and application of these separate technologies in order to identify the right approach for successful integration. Understanding the theory behind the technologies would empower farmers to avoid common mistakes in aquaponic production, system design and management and will enable them to farm at optimal levels.

Aquaculture production and management is divided into: Aquaculture management which focuses on the fish and their requirements, and water management which can be seen as the most important aspect of aquaculture as water quality sustains life and determines the wellbeing of the project. The water quality and its treatment also determine the performance of plant growth if it's introduced to a hydroponic component.

Hydroponic plant production requires a nutrient solution to be maintained and supplied to grow crops. Most crops especially leafy vegetables and herbs grow well in aquaponic nutrient solutions. If plants are grown (such as tomatoes) which require more calcium this have to be manually added to the existing aquaponic solution, mainly only calcium, potassium and iron is supplemented in aquaponic systems. Growing crops in greenhouses add to the benefit of closed controlled farming which limits the loss of energy and protects the plants from external climatic factors or limitations. Greenhouses can be scientifically modified to produce an artificial environment that enables farmers to produce throughout all seasons.

Before beginning an aquaponic project it is important to go over the aquaponic checklist and to manage fish and plants individually to their optimum requirements. Aquaponic greenhouses can be even more improved through a ecological approach towards its building design and layout features by energy efficiency measures and the capture and conservation of energy with the help of insulation. It is recommended to do careful planning and research before beginning a project with a high capital investment.

Chapter 4 - Experimental Case Study: Welgevallen Aquaponics Facility

4.1 Introduction

The Welgevallen Experimental Farm (WEF) located in Stellenbosch between the University's Coetzenburg sport fields and Paul-Roos High school (see figure 1.1 and figure 0.3 in appendix C) was approached to conduct a small scale aquaponic study. The empirical study was approached to identify design flaws, component analyses and the daily management procedures and challenges of aquaponic systems. The study has a hands-on practical approach to system analysis and problem solving.

The site in the featured study was retrofitted and constructed with affordable and locally available materials. Linking to Chapter 3 the study aimed to investigate the use of existing components and design at WAF and report on the practicality and performance of them. The study aimed to demonstrate the growth potential of aquaponic crops and challenges associated with producing them.

4.2 Background

WEF was purchased by the University of Stellenbosch in 1917. It hosts the Department of Agronomy and Aquaculture Division under the Faculty of Agrisciences and features several class rooms, laboratories, controlled climate chambers, aquaculture chambers and greenhouse tunnels (see figure 0.3 in the appendix C).

WEF was approached by a private mining company, Richmond Mining and Exploration in late 2012 who donated and constructed Welgevallen Aquaponics Facility in 2013. Their aim was to assist the University to advance research in aquaponics and to better understand the potential of waste recycling in aquaculture. I was fortunate to be involved in the planning, budgeting and building process of the facility which supplied rich experience on the subject.

The climate and location for WAF is typical of that of the Western Cape which has a dry hot summer and a wet cold winter. The cool temperatures of winter have proven to be one of the major challenges for the WAF which will be discussed later.

Photo 4.1: The initial Aquaponics Facility at Welgevallen Experimental Farm

Welgevallen Aquaponics Facility was constructed at an existing aquaponics system housed in the greenhouse in photo 4.1. The previous facility failed to take off and was no longer in use. This was partly due to incorrect design. It had been an experimental facility and the pipe sizes were too large for the water flow. In addition the fish tanks had been custom made but were square and lacked the strength to hold all the water when full. This was a problem because firstly it was square tanks (of photo 4.1) which created dead zones (areas in the square corners which did not get fresh replaced water) and secondly it was lumpy and had to be reinforced to stay upright. It is recommended to use round tanks which evenly displace pressure to all sides (Lekang, 2007). Furthermore the aquaponics facility that existed there used gravel beds to grow plants; this was not however a problem as gravel based media is suitable for aquaponics. I modified the gravel beds to deep-water culture beds which were personally easier to work with and it created no accumulation of nutrients.

A decision was taken by the representatives of WEF, Richmond Mining & Exploration and I to redesign the system. This redesign elected to separate the systems so that the plant grow beds was housed in the greenhouse tunnel and an open field next to the tunnel could be utilised as the site for the aquaculture facility. The reason for this was that there was not enough space to position the aquaculture facility inside the greenhouse and the adjacent open field posed the only viable option to position it. The plants needed to be housed in the greenhouse to provide shelter from the weather especially in the late rainy months. The greenhouse had no electric fan or light thus the full capability of the greenhouse could not have

I removed the gravel in the grow beds and dumped it all on the aquaculture site as it is important to keep the site clean and free of vegetation.

4.3 System analysis

Welgevallen Aquaponics Facility summarized design description

As illustrated in figure 1.1, the WAF was designed into a unit which comprises of three separate 10 000L circuits, (Line 1, Line 2, and Line 3). They were kept separate to enable comparative studies and to test various technologies.

Each of the individual lines start off at the 2 x 1500L vertical fish culture tanks (1), these each flow through a vertical silo 1100L waste separator or settler tank (2). To get rid of the CO_2 a small 50L tank in line 3 was installed, positioned between the waste separator and biofilter (3). After the solid waste and particles settled on the bottom of the cone shaped settler tanks the water would flow into a 900L flatbed biofilter (3).

After the water has flowed through the 'Aquaculture Area' the water flows by gravity to the grow beds (4) in the 'Grow Bed Greenhouse Tunnel". Line 1 and Line 2 flows through separate 5660L deep water culture (DWC) grow beds and line 3 flows through a grow bed that's divided into three 1330L compartments filled with (different/ a) growing medium. The water that passed through the grow beds is drained into the sump tanks (5) which are equipped with automated submersible pumps that constantly pump water back to the fish culture tanks (1). The drainage of grow beds 1 and 2 is a simple stand-pipe which overflows to the sump when water level breaches the rim of the drain pipe. Grow bed 3 has a series of three automatic bell siphon drains which allows water to fill up and drain at a desired level. The water supply in the whole system is regulated by three floating ball-valves located in each biofilter; these fill up water lost due to cleaning, evaporation, fish and plant use.

The additional equipment

All the water pumped from the sumps flows through UV filters to destroy any hazardous pathogens that might cause fish disease. The fish and plant root zones require oxygen and thus oxygen needs to be supplied. We used 2 x112W compressors to supply the 6 x 1500L fish tanks and 3 x 900L biofilters with air. We used one 112W compressor and a centrifugal blower to supply the plants' root zone with air.

To heat the water heatpump was installed which heated the water through secondary heat exchange (this will be explained in detail later). The heatpump was connected to a standard swimming pool pump which circulated the water for the heatpump to work.

The pipes that were used in the system was 50mm PVC pipes that transported the water between the fish tanks (1) to the sump (5) and 20mm HDPE pipes that transported water pumped to the fish tanks. As seen in photo 4.2 the facility consisted of a greenhouse tunnel that had vented mesh side panels allowing air to pass through. It also had rooftop vents to allow heat and humidity control.

Photo 4.2: Outer view of the Facility with a 3D model for clarity.

The aquaculture area had a corrugated roof for protection against rain and sun. Sunlight may cause algae to grow in the fish and bio filter tanks reducing its efficiency.

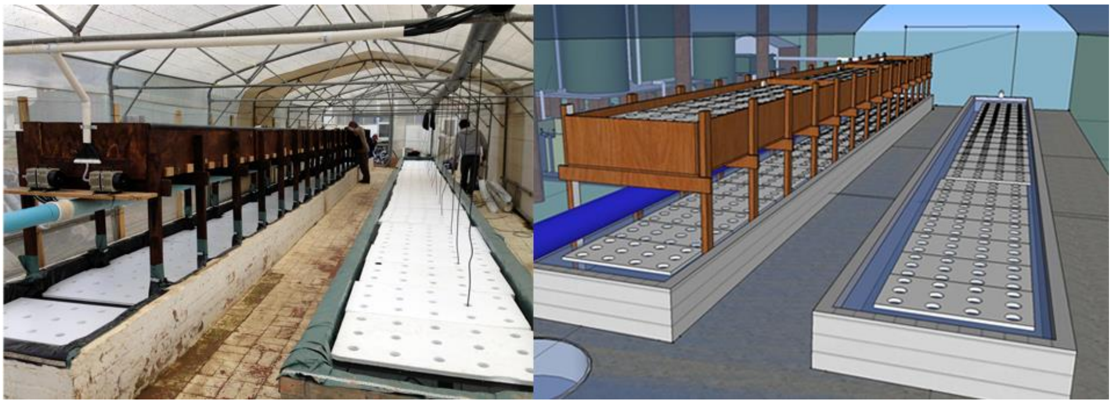

Photo 4.3: Inner view of greenhouse with a 3D model for clarity.

Extruded polystyrene was used as floating rafts in grow bed 1 and 2. In the wooden grow bed 3 a Light Expanded Clay Aggregate (LECA) and a recycled plastic product called 'Artyrock', made of recycled plastic that has been melted and crushed into small aggregates were used.

4.4 Daily Management

The daily management of WAF consisted of:

- Fish feeding three times a day;
- Checking fish behaviour;
- Checking water flow, pipes and pumps;
- Checking air flow and aerators;
- Checking heat pump and water flow;
- Checking plants

Other duties which were performed from time to time were:

- Draining settler tanks every third day;
- Cleaning the biofilters every second month;
- Harvesting plants that produced continuous produce like spinach and tomatoes;
- measuring and responding to water temperature, nitrite level, nitrate level, pH, dissolved oxygen levels and ammonia once a week;
- Cleaning vegetation around the site;
- Repairing shade nets, leaking pipes, blocked pipes,

- Cleaning algae and vegetation growth off water;
- Managing the growth of plants

Feeding and fish behaviour

The most time consuming labour at the site was feeding the fish. Average grown out fish require to be fed 2% of their own bodyweight. While feeding it is important to observe the behaviour of fish feeding. Healthy fish behaviour is generally observed as fish that have a healthy appetite. A 'feeding frenzy' –when fish aggressively compete for food at the water surface it is seen as a sign that fish are in a healthy state with a steady metabolism and that they are not under any stress.

Fish behaviour can further be observed in the way they move around in the fish tank. A healthy movement is seen as actively swimming around and interacting with other fish. When fish gather together in the bottom of the tank it is usually a sign of stress or disease.

When the water dissolved oxygen levels are too low the fish will gasp for air on the water surface, this requires the immediate increase in oxygen input into the water or the removal of some fish from the tank to decrease the stocking density of the fish tank.

Any unusual behaviour is a sign that requires immediate action to avoid loss of fish. Fish stress needs to be monitored as this can be as a result of natural or man induced events. Stress influences the behaviour and the disease susceptibility of fish. Stress is usually the primary cause of fish fatalities.

The fish tanks and grow beds require aeration to keep the organisms functioning properly. Fish in small circular tanks require aeration because the diffused oxygen from the air has a limited surface area and cannot provide fish with sufficient oxygen, especially when they are stocked at a high density.

Oxygen is needed by the plants' root zone to facilitate active transport of nutrient uptake. This also helps breaking down ammonia that the biofilter could not break down.

Cleaning

A routine cleaning action was part of the operation. The biofilters required that solids and algae be removed from the biofilter tank manually and the bio growth media sheets and nets have to be cleaned with a high pressure hose (see photo 4.4)

The nets and bio growth media is hard to remove but easy to do with a compressor. Cleaning the biofilters unfortunately destroys the biological processes and bacteria in the biofilter thus care should be taken to only remove the solid organic materials and algae and preserve bacteria.

As for the rest of the site, it is important to remove vegetation and weeds surrounding the area to ensure that the facility operates under control and prevents any disease, pest or pathogen outbreak.

Photo 4.4: Cleaning biofilter media.

Waste management

The only waste that the system had is solid waste from the fish which was flushed out at the settler tank and plant material.

I made use of a composting bin to further reduce waste from the system. A container was filled with sawdust which is high in carbon and placed it next to the aquaculture settler tanks. All the solid waste removed was placed in the composting bin. The sawdust assisted in masking the strong ammonia smell. A fellow researcher placed enzymes into the composting bin which accelerated up the breakdown and nitrification process. Further studies are yet to prove the efficiency of composting fish waste. Theoretically it makes sense not to waste the solid fish waste which is very high in nitrogen and nutrients.

4.5 Technical Analysis of WAF

The primary problems WAF experienced were associated with plumbing and water temperature control. Only as winter approached some problems emerged mainly due to the changing season such as cooler water temperatures and heavy rain, which called for changes in the system.

It was found that our 50mm PVC pipes were too thin which caused pipes to block with solid waste particles and fish got stuck in the water removal pipe in photo 4.5-a It was confirmed by a Lennard and Rakocy (2013), that our pipes were too thin and had too many bends (see photo 4.5-a). I found that it was easier to use standard sizes and thread standards. In the photo 4.5-c I used a wrong thread (grey connector) which I forced onto the green pipe connector and eventually stripped the green connector. I had to cut off the green pipe and install a new standard thread connector which was easier to join. Screwing on bulkhead seals (4.5-d) too tight caused the seals to pop in the middle which caused leaks. Moving the central biofilter waste removal pipe (4.5-e) to the side and installing a stilling box (4.5-f) over the waste water entry pipe helped separate the solids more efficiently and kept more solids out of the biofilter. Using an overhead waste removal pipe 4.5-h) proved very difficult to work with because it was in the way when I wanted to catch fish; in addition it proved impossible to drain the fish tank with the overhead water removal pipe. A bottom central standpipe would have worked better.

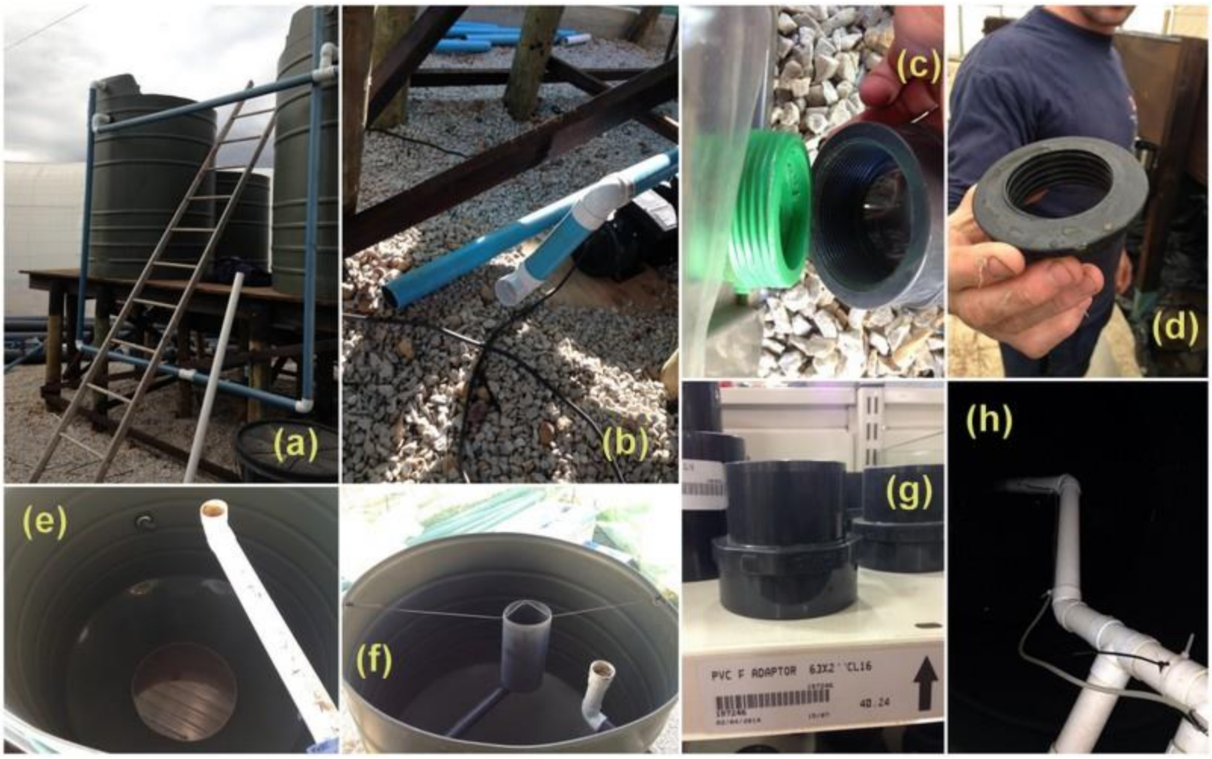

Photo 4.5: Plumbing of WAF.

4.6.1 Aquaculture tanks

The aquaculture tanks were simple water storage tanks that were modified with pipes and fittings. As the standard height for these water tanks were 1.5 meters it proved difficult to access the fish.

There was a few instances where fish swum into the extraction pipes which blocked the water flow and caused or tanks to overflow. The extraction pipes had to be modified in which I inserted a cable across the bottom end to prevent fish entering the pipe and an airlift pipe was inserted into the water removal pipe (see figure 4.1). The airlift concept works that the compressed air that is released inside the water removal pipe causes the water to remove faster and removes a higher head of water due to the rapid rise of air bubbles which push the water out with it.

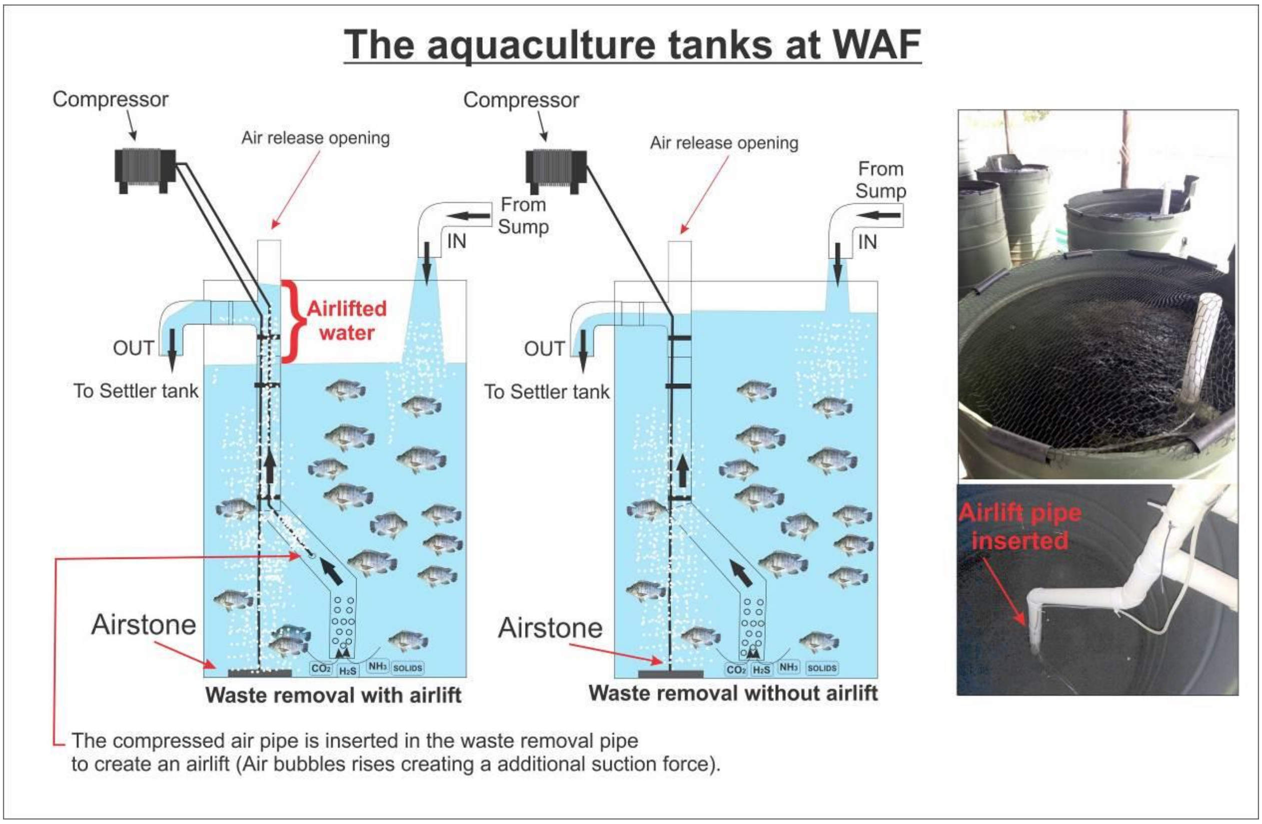

Figure 4.1: Fish tanks and airlift description at WAF.

Because of the small air-to-surface area (low air diffusion surface area) of the water in the tanks I needed to add additional air. I inserted an air stone (a fine porous stone which gradually released diffused fine bubbles of air into the water) which was coupled with the compressor to deliver air to the fish in the tanks.

Several problems were encountered with fish that jumped out of the fish tanks (photo 0.14 in Appendix C) which I was forced to mitigate by covering the tanks with netting.

The overhead suction waste extraction pipe (h, in photo 4.5) worked fairly well and the tanks were clear and solid waste removed. When the airlift was installed the, it merely dropped the water level as the airlift principle is there to lift water. I did this to see if the water will drain faster and also to drop the water level as some of the tanks had overflowed a few times due to blockages and air bubbles in pipes. No notable improvement has been noticed in water clarity when compared to the non-airlift system.
One of the disadvantages of the overhead suction pipe is that the tank is difficult to manage, as it is in the way if you net fish or clean the tank.

4.6.2 Waste Separator Tanks

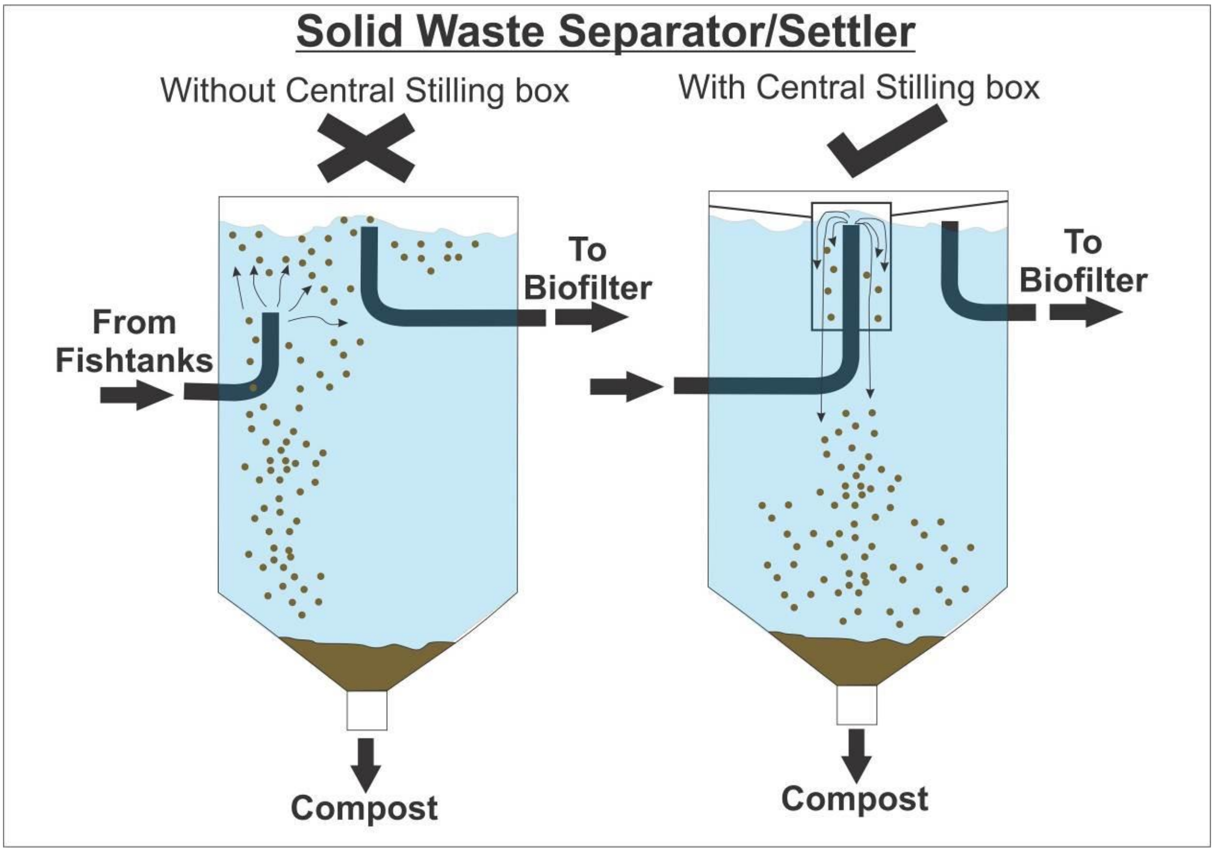

Figure 4.2: Solid Waste Separator-Modified swirl separator.

The solid waste separator (figure 4.2 above), or settler tank, is important to separate solid waste from the biofilter. It needs to be known that nutrients required by plants are not solid/organic-matter waste as associated to the use of terrestrial compost but rather soluble nutrients which is dissolved in water.

The solid waste which is high in HN3, H_2S, and CO_2 needs to be separated from the biofilter to prevent the biofilter from building up with solid waste which results in efficiency loss. Cleaning the biofilter can be a difficult task (discussed later).The swirl separator/waste separator (circular gravitational waste removal tank) (shown in figure 4.2) allows for the heavier solid particles to accumulate in the bottom of the settler tank..

Lekang (2007), states that swirl separators require uniform water flow at a specific drum diameter to achieve optimal efficiency, otherwise particles would flow out of the separator. The system at WAF is designed with submersible pumps which pumps water irregularly every 5-6 minutes triggered when the sump tank is full. The auto pumping causes an irregular flow in the separator which may be the cause why the solids did not settle in the initial design without the stilling box illustrated in figure 4.2 on the left.

It was found that using a simple ‘central stilling box’ forced the solid particles down more efficiently in water with irregular flow rates compared to the tanks that had no stilling boxes (see figure 4.2). This means that the stilling boxes provided an additional way to force solid waste particles to collect together in the bottom centre. The central waster release covered by a stilling box helped to collect and push down solids with the force of entering water.

To investigate the use of the only waste product generated by the system, I flushed the settler tank every second day and used the waste water/solid waste mix in a composting box. The composting bin which consisted of wood chips, plant material and soil proved to remove much of the strong odour which the waste water had.

4.6.3 Biofiltration

The biofiltration process is the most important process in RAS (Recirculating Aquaculture Systems)/Aquaponic systems. Biofiltration is also seen as the most difficult component in aquaculture systems to manage correctly (Badiola, Mendiola & Bostock, 2012).

The biofilter primarily works in two ways; one it breaks down nutrients (not solid waste) with the help of nitrification bacteria and secondly it oxidizes the nutrients through aeration and oxygen in the water. The nitrification process illustrated in figure 4.3 below shows the steps of nitrification.

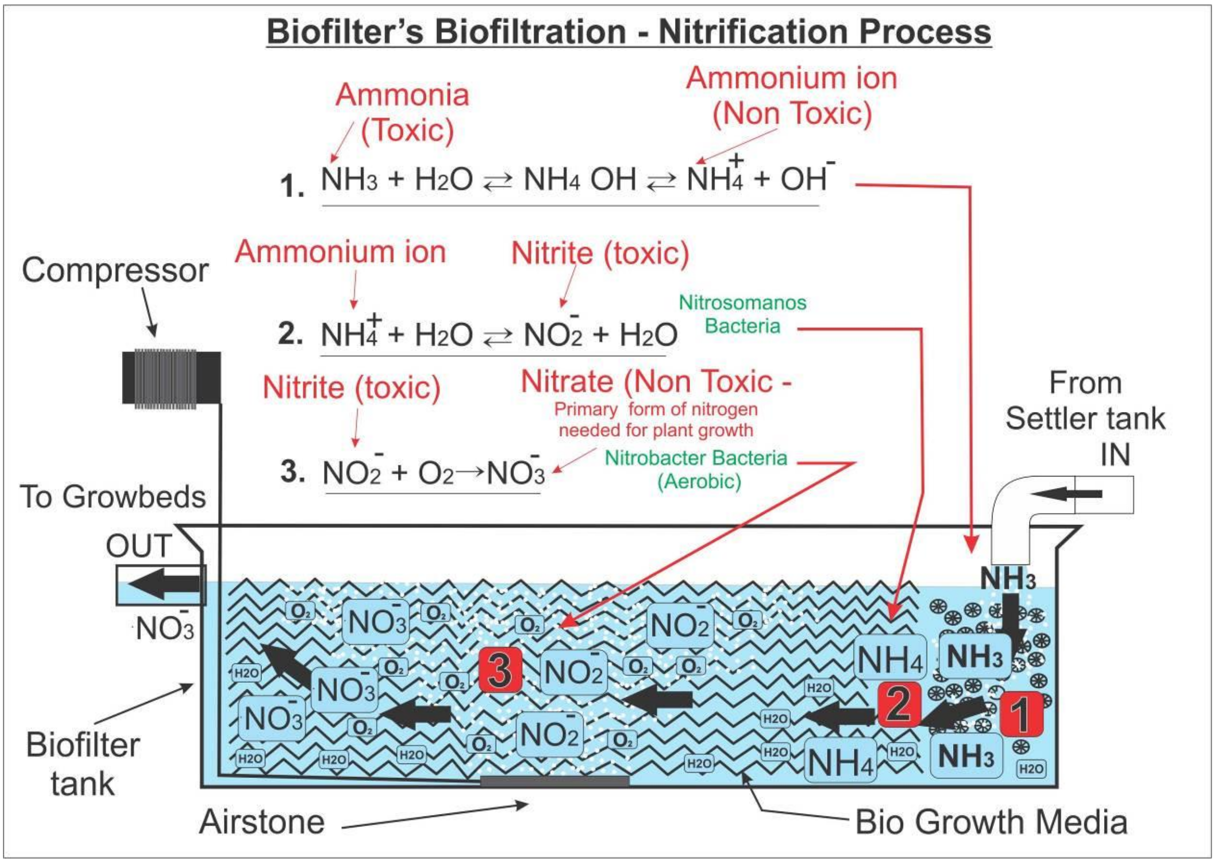

Figure 4.3: Nitrification process in the biofilter.

The nitrification process works by breaking down toxic ammonia to an ionized ammonium form. The Ammonium ion gets broken down to nitrite which is then further broken down to nitrate which is the primary nitrogen component for plant development. The breakdown from waste to beneficial nitrogen is the same in the aquaponics process as it is in soil processes as organic waste compounds are broken down and converted to nitrates (Prosser, 2005).

I used square 900L tanks as biofilters, and placed bio growth media (indicated in figure 4.3 as the jagged lines) in the beds for bacterial growth. To improve the process I placed compressor connected airstones between the bio growth media.
I added an additional bio media and hair curlers rolls to the biofilter to improve the process, this was done because the hair curlers and bio media are small plastic objects with a large surface area for bacteria to grow on which caused nitrification to take place, the objects needed to be round that it is able to spiral around enabling an aerobic process.

The tanks were drained and cleaned twice, which had to be done to modify and clean the system. This however caused the bacteria to deteriorate in the biofilters (because the bacteria requires nutrients and a water environment to survive) as well as a decrease in nutrients in the water which we could notice in the plant growth in the grow beds. Some plants started to show signs of nutrient deficiency and the tomatoes started to form mildew. It is thus recommended to design biofilters efficiently to require as less as possible cleaning.

4.6.4 Grow beds

The system were started using the two predominant aquaponic growing techniques in the three grow beds which is gravel based/substrate media and the deep water culture (DWC) method.

Gravel based substrate media
Gravel based substrate media is gravel that supports plants to remain upright and supplies plants with nutrient through flooding and drainage of nutrient rich water.

A mixture of light expanded clay aggregate (LECA) and a recycled plastic aggregate was used in grow bed 3 in figure 4.4. For gravel based media it is required to use auto drain bell siphons which drain the water and allows oxygen to flow through the gravel to aerate the root zone of plants. The bell siphon draining system is illustrated in figure 4.5 below.

I found that the gravel based media tended to form an accumulation of nutrients around the inflow areas. There were no evidence of root rot in plants and the bell siphons worked without problems for the 6 months period of the trial. The only problems identified were that the three grow bed were divided into three compartments which all drained individually and would sometimes drain together which caused a surge of water to be drained that were too big for the sump tank to handle, this however is a design problem not a LECA problem but because ebb and flood systems drain this way it is worth mentioning. I had to install a flood control tank (see photo 0.12 in Appendix C) to control the surge and allow a constant flow to the sump tank to be pumped to the aquaculture tanks.

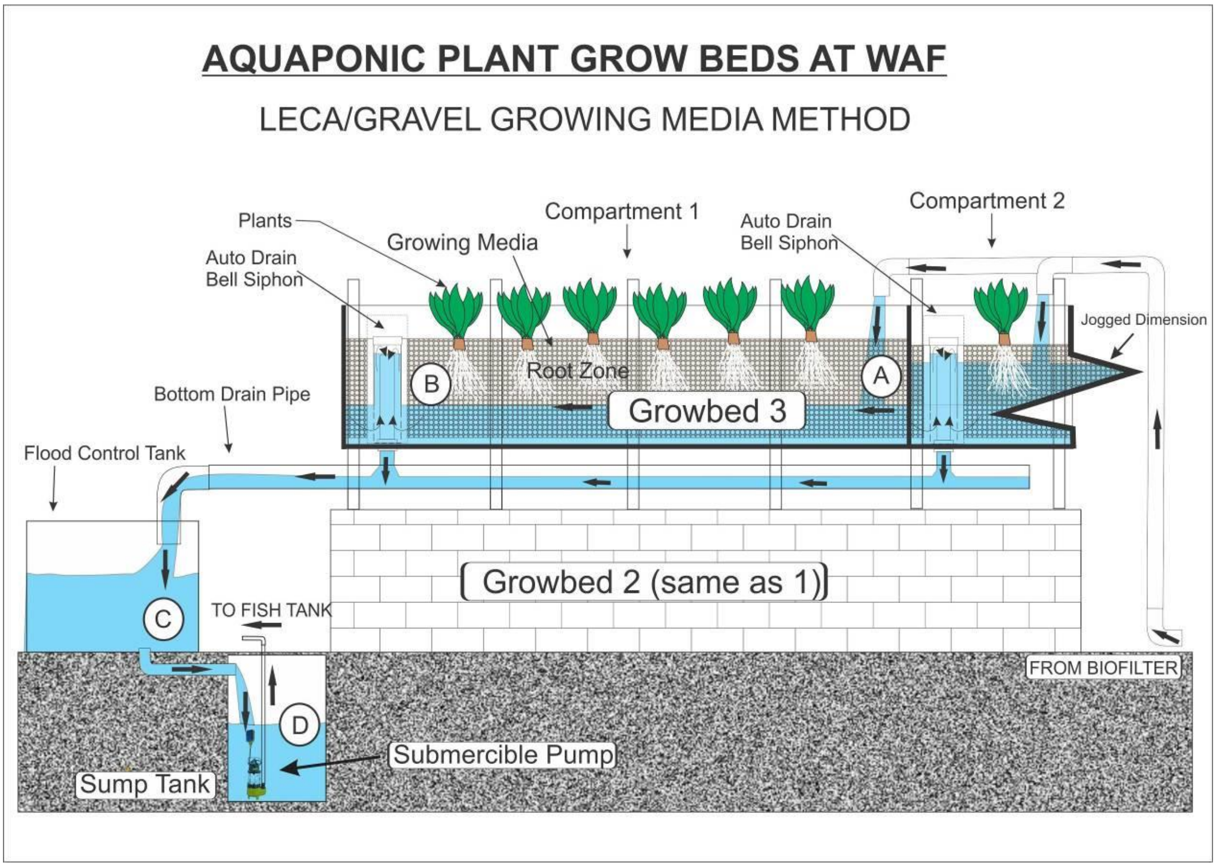

Figure 4.4: Grow Beds - LECA/Gravel Growing Medium Method

Labels of figure 4.4:

A-Water inflow

B-Auto drain bell siphon (more explained in figure 4.5).

C-The flood drain tank (also shown in photo 0.12 in Appendix C)

D-The sump tank: the lowest point of the system where the water gets pumped back again to the fish tanks.

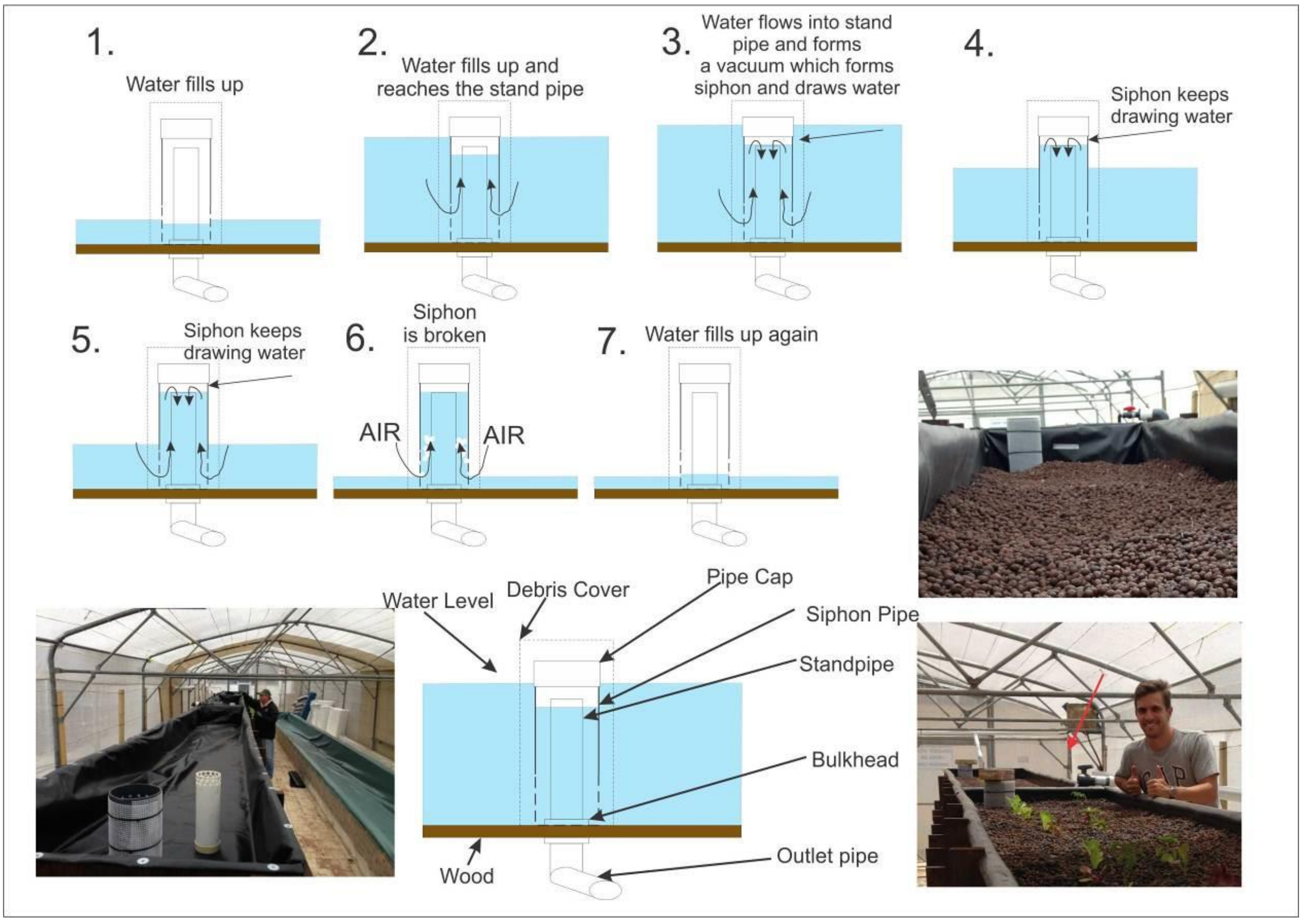

Figure 4.5: How an auto drain bell siphon works.

The Tomatoes grew well in the LECA substrate; the one plant in photo 4.20 carried over 120 tomato fruits at one stage but had to be taken out because it got infected with mildew which was due to the rising humidity of the winter season.

Deep water culture method

Labels of figure 4.6:

A-The water inflow.

B-The root zone of the plants submerged fully in water.

C-The water outflow standpipe.

D-The sump tank, the lowest point in the system in which the water gets pumped back to the fish tanks.

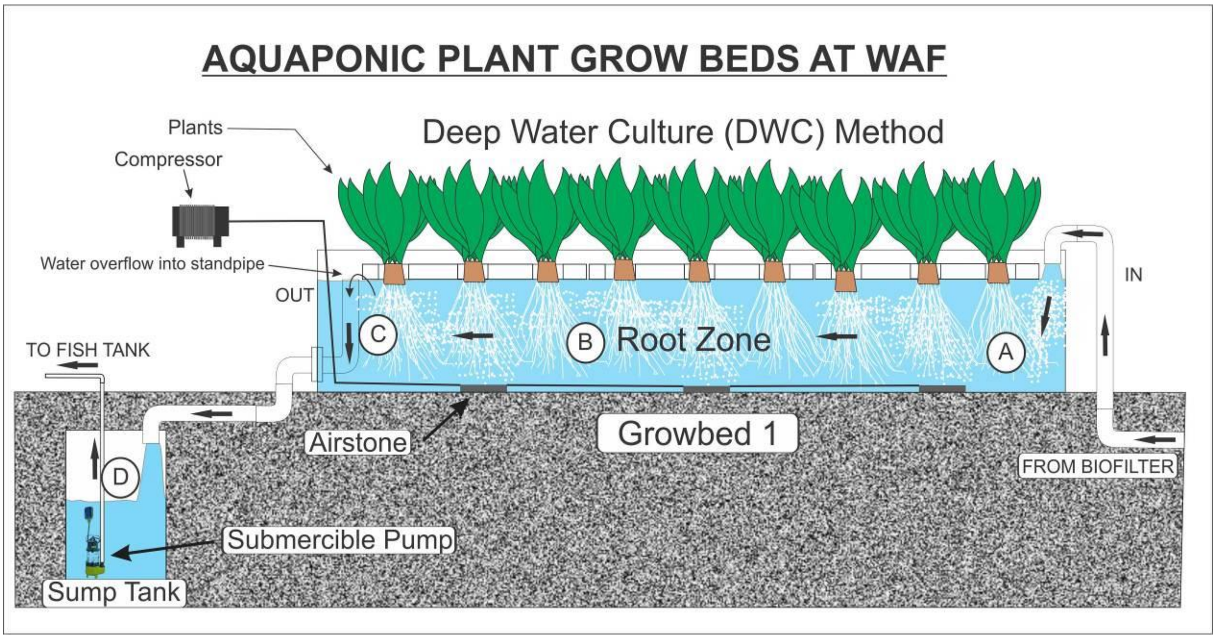

Figure 4.6: Grow Beds - Deep Water Culture (DWC) Method.

The deep-water culture method was used in grow beds 1 and 2. The method can be described as plants that float on top of aerated water with the aid of a floatation medium. I used extruded polystyrene which was donated by a local roof insulation company. I drilled 50mm holes into the polystyrene (see appendix C photo 0.10) into which I placed a standard growing/propagation pots in the drilled holes. The cups and polystyrene acts as structural support for the plant to develop.

The Deep Water Culture (DWC) method is based to allow plants take up dissolved soluble nutrients in the water. The plant's root will dangle in the water and absorb the nutrients provided and in that manner clean the water to be supplied to the aquaculture tanks. This function the same way plants grow in soil in which the root zone absorbs nutrients from the soil.

The DWC method has a constant water level and requires aeration to prevent root rot and enable to plants to take up nutrients. The DWC method proved to work the best in the WAF as it showed the biggest plant and root growth development and in terms of practicality it were also easier to work with.

4.7 Fish Management

It was decided to use Tilapia (Oreochromis mosambiccus) in the systems because they did not require any permits and was readily available on Welgevallen Experimental Farm. I however required more Tilapia to fully stock the system and experienced a hard time finding local suppliers which had affordable and sizeable Tilapia.

A local farmer gave me permission to net Tilapia in one of his irrigation dams. The attempts however were unsuccessful but the issue was resolved by Elsenburg (a state owned agricultural research facility outside Stellenbosch which have an aquaculture facility) which donated 60kg Tilapia on the 11th of March 2014.

Before the Tilapia were in the fish tanks I weighed them to determine the amount needed to feed them. I fed the Tilapia 2% of their total mass two to three times a day. It proved very time consuming being solely responsible for the fish.

The extra Tilapia was successfully introduced into the system and I took precaution with handling them according to the prescribed methods of aquaculture management. Once the Tilapia was introduced I allowed the system to run for three weeks to enable a build-up of nutrients and allow the nitrification bacteria to grow in the biofilters.

In April 2014, problems started to develop as the season turned and the fish started to show signs of stress and loss of appetite. At the end of April 2014, the water temperatures reached 15°C when the fish stopped eating and showed a complete passive behaviour. All the fish were taken out of the system and placed in a secured and warmed fish greenhouse which is located on the Welgevallen Experimental Farm.

The fish regained satisfying behavioural characteristics after a few days in the warm water at the greenhouse. I fed the fish there until a heat pump was installed for the WAF aquaculture tanks.

The heat pump heated the water between 21-25°C and proved adequate for the fish. The fish tanks were moved back to WAF in the middle of April 2014, and found that the fish showing no signs of stress other than that of the transporting and handling.

4.8 Plant production

Seedlings

With the initial fish I had I allowed three weeks for bacteria to develop and nutrients to build up. With the initial amount of fish in the tanks-on the February the 6th 2014, I bought plants at a local nursery, a selection of herbs, a root plant and vegetables were placed in the grow beds. The varieties that were used were: Basil, Beetroot Bijou Lettuce, Bright Light Spinach, Cherry Tomatoes, Chives, Green Oak Lettuce, Navada lettuce, Red Mustard, Swiss chard Spinach

The motivation for planting was to identify how the different random selection of plants adjusted to the aquaponic environment and to monitor which varieties perform and assess the common problems that arose.

Photo 4.6: Planting seedlings into the Grow Beds at WAF.

Lettuce varieties

On March the 3rd 2014, the lettuce plants were harvested which were less than 4 weeks old. They produced healthy firm leaves but however had a bitter taste which was probably due to a phosphorous deficiency often associated with aquaponic produce (Kempen, 2012).

In the 6th week after planting the lettuce plants reached 1 meter in height (see photo 4.8) and started to bolt and produce seeds which attracted aphids to the flowers. I removed the lettuce plants in the 8th week of their planting (see photo 4.9).

Photo 4.7: Aquaponic Produce - Healthy Nevada lettuce plant in DWC (6 weeks old).

Photo 4.8: Aquaponic Produce - 100cm Green Oak Lettuce plant in DWC (6 weeks old).

Photo 4.9: Aquaponic Produce – Large Green Oak lettuce plants from DWC method.

Spinach varieties

Plants like the spinach varieties were late bloomers which only peaked around the 25th of March 2014, after 7 weeks of planting. They produced however remarkable results (see photo 4.10 and 4.11) being very firm and broad leaved. The Swiss chard variety produced the best results in growth and leaf quality. We harvested leaves from the spinach varieties on a weekly basis. The plants continued to improve as the winter approached. It was found that the spinach growth performance was considerably better in the DWC method than the spinach grown in the LECA/gravel growing medium.

Photo 4.10: Aquaponic Produce - Bright Lights Spinach in DWC (9 weeks old).

Photo 4.11: Aquaponic Produce -Very healthy Swiss Chard Spinach Plant in DWC (9 weeks old)

Photo 4.12: Aquaponic Produce -Very healthy Swiss Chard Spinach Plant in DWC (10 weeks old)

Red Mustard Leaf

The Red Mustard's growth rate was similar to that of the other lettuce varieties. It however peaked at 6 weeks old producing very large leaves and exceptional spicy flavour. Signs of tip burn[11] appeared on various leaves which were a possible indicator of a calcium deficiency. The calcium deficiency is argued to be a likely cause as calcium is a mineral that needs to be supplemented to aquaponic processes as this is not a mineral generated or wasted through the aquaponics fish feed and waste collection process.

[11] A disease of the potato, lettuce, and other cultivated plants characterized by burning or browning of the tips and margins of the leaflets and caused by loss of water due to excessive heat and sunshine.

Photo 4.13: Aquaponic Produce- 70cm across healthy Red mustard leaf plant in DWC (6 weeks old).

Cherry tomatoes

It was found that the cherry tomatoes grew rapidly and started to flower and bear fruit within 4 weeks. The plants in the DWC medium had to be supported by string to trellis the tomatoes for support. The plants in the LECA medium tended to grow flat and required no trellising.

The cherry tomato's developed well until beginning of April when the humidity levels increased and signs of mildew appeared which spread rapidly across the tomato plants.

The tomatoes' skin was too soft and many small fruits perished under light pressure of the plant. It appears that the lacking calcium is the reason for weak fruit development. Fruit and plants' cell walls need calcium to keep a frim crisp structure.

Photo 4.14: Aquaponic Produce- 120cm high cherry tomato plants in DWC (7 weeks old).

Photo 4.15: Aquaponic Produce -Healthy and heavily carrying cherry tomato plant in LECA mix (7 weeks old).

Basil

The basil plants grew very well and produced great flavour. The basil were harvest ready within a month and produced well balanced green leaves which did not show any sign of nutrient deficiency in the early stage. After 6 weeks the leaves showed signs of an iron deficiency as this was a nutrient not supplied by the fish as well as the leaves indicated a yellowing from the edges to the middle of the leaf. Some of the basil plants started to bolt (shoot seeds) within a month which reduced leaf growth and efficiency.

The basil showed a better performance in the DWC method than that of the LECA medium grow bed.

Photo 4.16: Aquaponic Produce - Basil plants in DWC (4 weeks old).

Beetroot

The beetroots have grown surprisingly well having developed a nice bulb within 10 weeks. The performance of beetroot growth was better in the DWC method compared to the LECA medium grow beds.

Photo 4.17: Aquaponic Produce - Beetroot plants from DWC method (10 weeks old).

Chives

The chive plants had a slow start but were already able to be harvested within 6 weeks. They grew to full size at week 7 to 9 and have shown no real nutrient deficiency except some 'tip burn' which could have been caused by a calcium deficiency or the warm greenhouse temperatures. The chives grow well in both the DWC and LECA substrate medium. They produced a very satisfying flavour and had nice crispy tubes.

Photo 4.18: Aquaponic Produce - Chives in DWC (9 weeks old).

Photo 4.19: Healthy rootzone of plants in DWC.

Photo 4.20: Tomato plant with mildew problems.

Seedling production

The 9th of May 2014, I decided to grow seedlings for the system. In photo 4.21 it can be seen that it took a weekend for the seedlings to germinate. After that they were left to grow out in the trays to a size strong enough to be planted in the greenhouse. It was done by in the following steps:

1. Sterilization of seedling trays;
2. Preparing a seedling nutrient and growing medium mixture (perlite and fine compost);
3. Placing the nutrient mixture in the tray holes;
4. Individually insert the seeds in the trays;
5. Place the seedling trays in a germination room;
6. Wait for the germination to take place and move the seedlings to a grow out room or greenhouse;
7. Water the seedlings daily with a mild nutrient supplement;
8. Wait a month for the seedlings to develop;
9. Plant the seedlings out into the grow beds.

See section 3.5.5 on seedling production which discusses the full steps for seedling production.

Photo 4.21: Seedling production.

4.9 Climate and Water quality

The aquaculture area

The climate in the Western Cape is characterized as being very warm and dry in summers and cold and rainy in winters. The water temperatures varied from an average of 25°C in the summer to an average of 13°C in the winter where frequent spikes in temperature occurred. The seasons are too short and temperature span is generally too great to farm with one species of commercial fish like Tilapia or trout.

The warmer summer months were well suited for the Tilapia and they grew well and show no signs of stress. In April the water temperature dipped to 15 degrees which caused all the Tilapia to stress by bundling together and stop eating. It should be noted that WAF was an open facility with only a mesh screen and roof for wind protection. As a result I had to install a heat pump and insulate the pipes and fish tanks (see photo 4.22). The heat pump used a lot of power which have a negative impact on the financial viability of the aquaponic venture.

Photo 4.22: Insulating the pipes and tanks to preserve heat during winter.

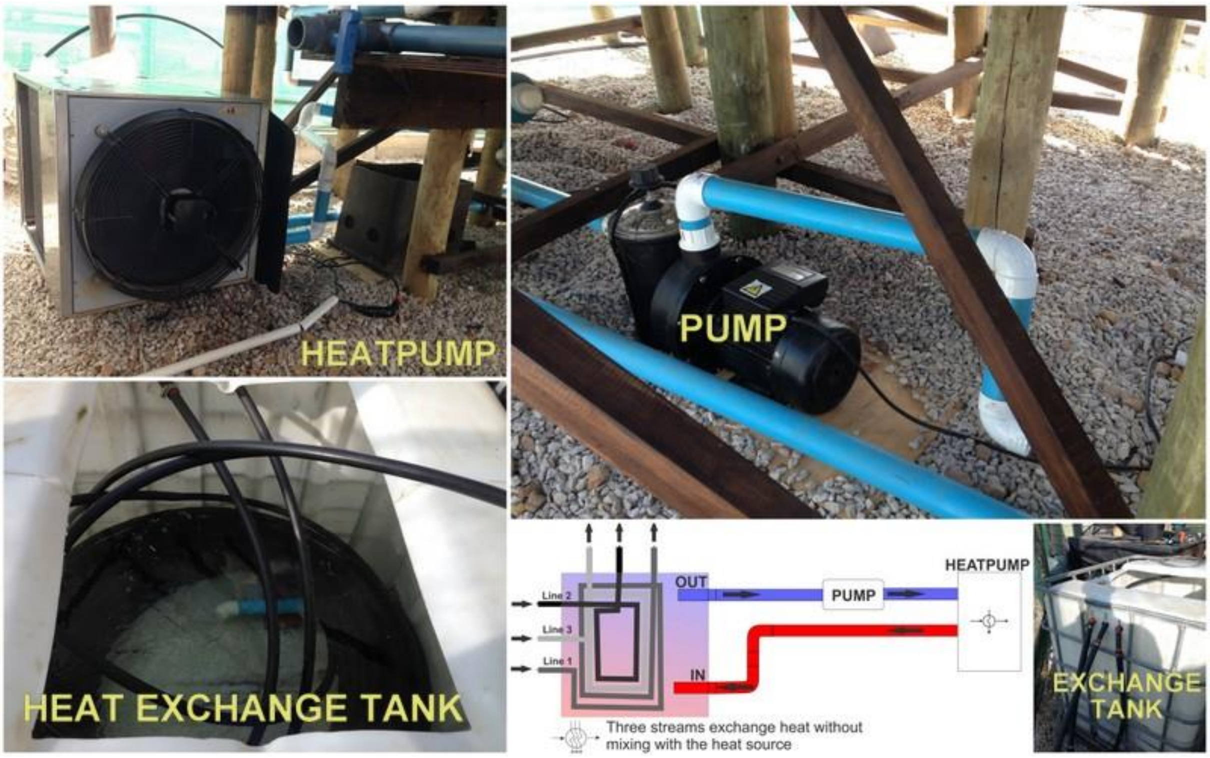

Photo 4.23: Water heating for winter using a secondary heat exchanger.

The system was difficult to manage separately because all the tanks needed to be heated in a manner that avoided the mixing the water of the three individual lines.

I developed a secondary heat exchange system (see figure 4.7) in which I installed a pool pump and heat pump to a tank of water that was insulated. The three pipes that came in from the grow beds were extended and coiled up in the heat exchange tank. The heated water in the heat exchange tank thus heated the coiled pipes which provided warmer water in the fish tanks. The water temperature in the fish tanks came up to 21°C and 25°C after installing the heat exchange system allowing to keep the aquaponic facility running through the winter.

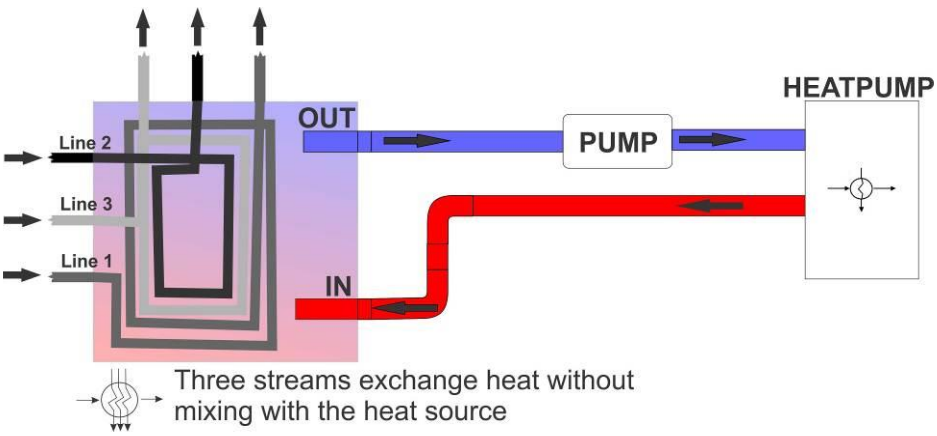

Figure 4.7: The secondary heat exchange system.

The greenhouse

The greenhouse worked well in the summer season. It had the basic features which were needed for aquaponic farming namely a waterproof roof, humidity and temperature vents. In winter however some out of season plants like the tomatoes suffered with mildew which been developed as a result of the high humidity levels. This was an external factor and could not be controlled from within the greenhouse.

4.10 Electrical problems

It was found that the heat pump drew a lot of current and continually tripped the circuit board switch. I was forced to install a slow curve circuit breaker which draws current on a gradual 'slower' basis and I also checked that the incoming three phase power were balanced.

In most RAS systems and other intensive systems any electrical error could cause fish fatalities. Backup systems and alarms are highly recommended for the safety and security of fish in a fish farm. It is also recommended to install cameras and sensors connected to a network which make operations much easier to manage and observe remotely.

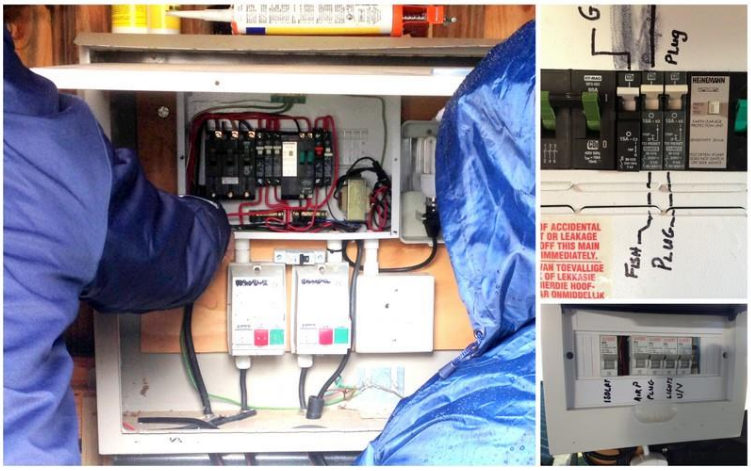

Photo 4.24: Be sure to set up the electrical system with the help of trained professionals.

4.11 Concluding Analyses

To analyse a system and identify issues that affect ecological, social and economic well-being of an aquaculture project it is best to look at the holistic view, to all the aspects of production namely; 'Inputs, Resource Use and Outputs', and categorize issues into local, regional and national level (FAO, 2010).The issues identified could provide information to what causes them and relate to other causes in the production cycle. This makes it easier to identify and address advantages and problems used to compile environmental impact assessments or project application documents.

Issues	Local (WAF)	Regional (Western Cape	National (South Africa)
		INPUTS	
Production of locally produced fish feed	+Low cost fish feed improved production costs	- Effect on wild fish stock used to produce fishmeal +Effect on fisheries communities and communities involved in feed production	- Effect on wild fish stock used to produce fishmeal
Labour	+Job opportunities and improved livelihoods	+Job opportunities and improved livelihoods	
Infrastructure	+New available Infrastructure available of Experimental Farm		
		RESOURCE USE	
Water	-Use of water for constant flushing and cleaning +Efficient water use due to recirculation of water +No waste produced and water pollution caused +Water quality is maintained and managed by the natural nitrification bacteria and plants.	+Efficient water use due to recirculation of water +No competition with other freshwater water resources +No waste produced and water pollution caused	
Land use/ Ecosystem	+Efficient land space use +Water is recirculated in closed loop +No competition with local freshwater resources +Fish species pose no threat to external ecosystem and biodiversity.	+Fish species pose no threat to external ecosystem and biodiversity. +No competition with regional freshwater resources	
Energy	- Use of energy to power compressors, pumps and heat pump. - No aquaculture room insulation		

	+ Insulated pipes and fish tanks +Pump energy is efficiently used by gravity flow design +Use of self-draining bell siphon grow bed drains which require no aerators +No need for tractors or mechanical equipment to produce crops.		
OUTPUTS			
Biomass (fish and fresh produce)	+ Potential biomass production (fish and plants) for hunger alleviation and food security +Providing a source of high quality protein	+ Potential biomass production (fish and plants) for hunger alleviation and food security +Providing a source of high quality protein	+ Potential biomass production (fish and plants) for hunger alleviation and food security -Possible competition with other common food markets.
Income	+Provision for income to people involved in construction and part time labour.		
Seedling production	+Grow own seedlings locally, saves money and cuts down on overall costs	+Support local seedling producers	
Fingerling fish supply	+ No cost involved to supply WAF with fingerlings -No support for local fingerling suppliers	+Collaborated with Elsenburg to supply us with fingerlings +No fishing in dams or other habitats. -No support for local fingerling suppliers	
Nutrients	+Nutrients are not wasted and is recirculated in a closed loop +Nutrients are used to grow fresh produce. +No eutrophication +Water quality is maintained and managed	+No pollution or environmental impact on regional watersheds or ecosystems.	
Diseases	-Stress from handling and water temperature caused minor fungal infection. -Lack of biosecurity	+No possibility for fish to escape to carry possible disease to fish in the external habitat.	+No possibility to spread diseases.
Chemicals	+No chemicals were used	+No chemicals were used,	

Escapees	+No potential escapee impact on local fauna and flora		

Table 4.1: Production Impact Analysis of WAF (Note: Positive (+) and Negative (-)

As Table 4.1 shows, WAF's aquaponic technology provides many positive issues in the production chain. In regular aquaculture production systems resource uses for inputs such as water is usually a negative issue as water use is high and treatment has an economic cost associated with it . If water is not treated properly (as is the case on many farms) the waste causes water quality deterioration downstream.

In terms of chemicals like herbicides, pesticides, and antibiotics, none of them can be used in an aquaponic system. Because of the symbiotic nature of being locked in a closed recirculating loop the water quality has to be of high quality for sustaining fish and plant health, no herbicides, pesticides can be used because it will kill the fish which is sensitive to water contaminants in the closed recirculating system. This will also prevent natural bacteria to perform nitrification, artificial chemicals break down the natural biofiltration bacteria that are the core of an aquaponic system.

In terms of biosecurity; usually with pond and flow through aquaculture it is very difficult to ensure that no species will escape and pose an environmental risk of spreading disease and inbreeding with native species. With recirculating technology such as aquaponics the risk don't exist as water is continually recirculated and reused in a secure closed system. Aquaponic systems do not require being located in the vicinity of rivers of large bodies of water thus ensuring that risks associated with escapees and spread of possible disease is reduced.

Strengths	Weaknesses
• Resource efficient food production. • Self-cleaning and recirculation of water • Can produce fish and plants together • Leafy plants grow well with no additional nutrient supplements. • Water quality is maintained	• System design requires professional help or extensive self-research. • Managing aquaculture and hydroponics can be technical and time consuming • Aquaponic systems require constant hands on management. • Climate and seasonal changes in temperature affects the productivity of the system
Opportunities	**Threats**
• Diversity of produce • Double stream of income(fish and produce) • Controlled environment farming is more resilient to external factors. • Largely undeveloped aquaculture industry • Using Nile Tilapia • Aquaponics support the biodiversity regulation. • Designing a aquaponics-specific greenhouse	• Design problems: High aquaculture tanks, thin pipes, not enough valves, efficient plumbing. • SA climate and large seasonal temperature differences. • High energy use in winter • Market of warm water commercial fish like Tilapia in South Africa not yet established.

Table 4.2: SWOT analysis of WAF experiment period.

4.12 Summary

The study has proven aquaponics to be very fairly simple and effective to produce fish and crops in a locally self-constructed system, but it identified that it requires a technical and specialist approach to produce high quality aquaponic fish and produce (this approach is discussed in chapter 3).

The aim of this study was to gain a better understanding of the practicality of aquaponics through the day to day production and management of the system.

The outcome of the 6 months spent at WAF was positive. The plants and Tilapia fish grew very well in the warmer months but the winter presented many challenges that were partly overcome by heating the aquaculture water and planting in season plants. It was found that the plants especially the leafy plants and the beetroot grew well with only aquaculture waste water as nutrient source. The fruit bearing tomato plant showed signs of nutrient deficiencies and has also been a victim of mildew which is prominent in humid climatic conditions.

According to the design it was found that the DWC planting method performed better and was easier to manage than the substrate media. The only waste that was produced was solid waste that accumulated in the waste separator and the waste had been successfully composted.

It was identified that electrical components should be installed by professionals to safeguard the aquaponic operations, emergency alarms and backup systems should be considered. It is advised to use thick pipes with minimum angles and to install valves between each water tank component.

Chapter 5 : Project proposal

Ntinga Co-Operative Limited

Urban Integrated Aquaculture Farming

Please note: There will be repetition in this chapter. This is intended because the project proposal is also considered a stand-alone unit.

5.1 Introduction

The University of Stellenbosch's Aquaculture Division (here after referred to as the University) was tasked to assist a group of African female urban farmers in Philippi, Cape Town to develop an urban aquaculture[12] farm, and set up a technical project plan to access funding from the Department of Trade and Industry.

The site is situated on the northern edge of Philippi and Mitchells Plain (see figure 5.1 on the following page), which is largely known as the Cape Flats (City of Cape Town, 2013a), which make up a low income area with widespread poverty and food insecurity (Battersby, 2011). Land in the Cape Flats and surrounding townships remains a contested resource due to housing shortages and industrial space (Essop, 2014; Knoetze, 2014; Sesant, 2014). This challenges urban areas to be used very efficiently.

Malnutrition rates in South Africa's urban areas are increasing; raising the question as to why this is a problem when South Africa is a food secure nation with a well-developed agriculture sector (McLachlan & Thorne, 2009). South Africa's aquaculture industry however remains largely underdeveloped in both regional and international terms (Rana, 2011; Department of Agriculture Forestry & Fisheries, 2013; Salie, 2014).

Fish is considered as an extremely nutritious food source having a unique nutritional composition containing a balanced amount of protein, fatty acids and essential nutrients (Murray & Burt, 2001; Cheung et al., 2010).

Currently government have embarked on a massive aquaculture development programme and placed regulatory and support measures in place. This creates the environment to rise to the opportunity and develop aquaculture to create jobs, grow the economy and support food security.

[12] The cultivation of aquatic organisms

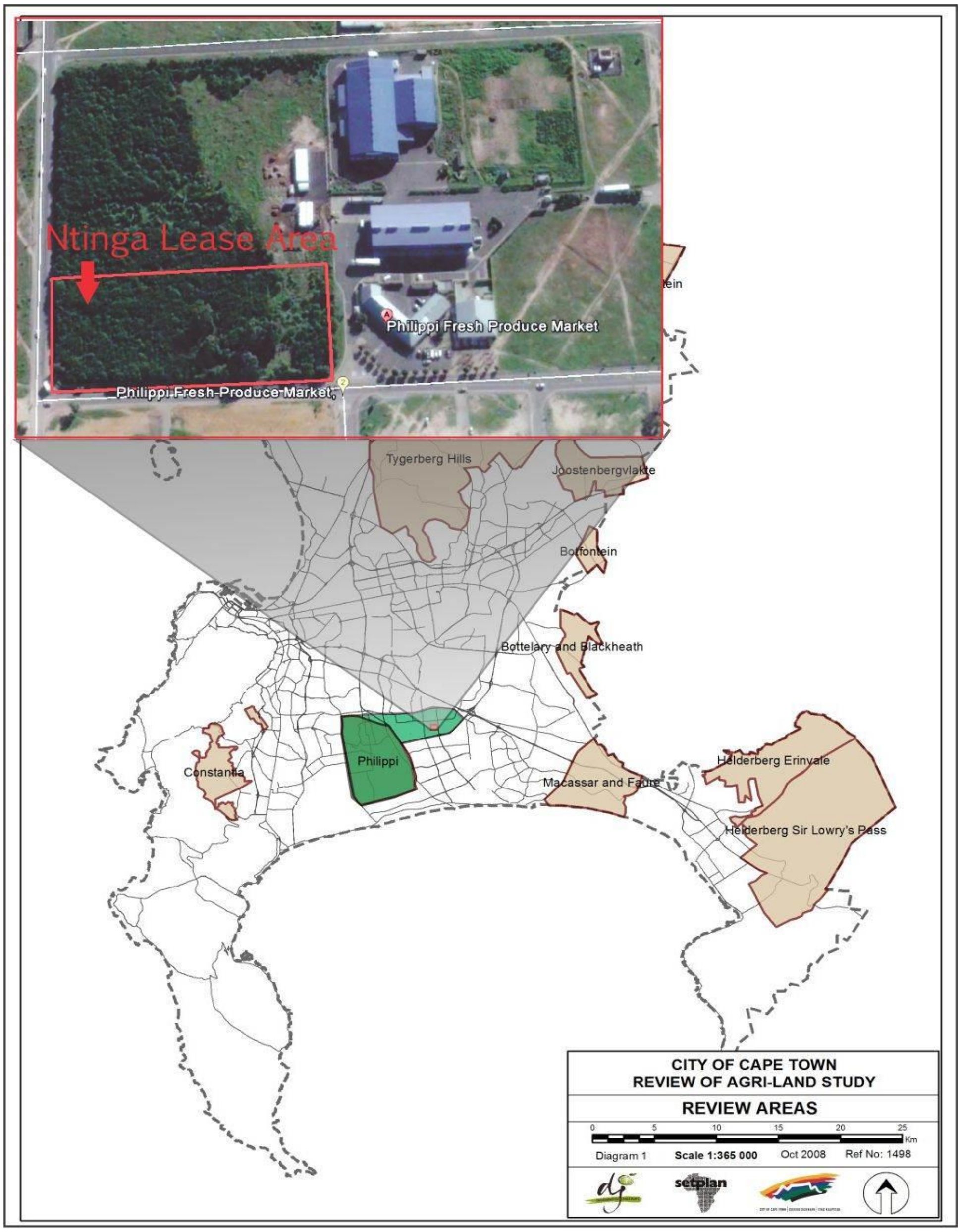

Figure 5.1: The location of case study of the lease area of the Ntinga Multipurpose Co-operative.

5.2 Methodology

Because the case study of this chapter is targeted at Department of Trade and Industry (DTI) funding grants. The project proposal has been done according to their guidelines. The information in project proposal is based on research and experience gained at WAF and academic research on aquaculture and hydroponics. The financial model was done with data and information gathered from academic research and market research.

5.3 Project Summary

5.3.1 Administration Information

Name of Co-operative: Ntinga multipurpose co-operative limited REG: 2013/ 012900/ 24
Main Business Activity: Agriculture
Physical Address: Informal Rd, Philippi East, Cape Town, 7781

5.3.2 Project Overview

The Ntinga Multipurpose Co-operative (NMPC) is a black women owned entity that was established in 2013 (See figure 5.3 for time frame). The Ntinga group come from various working backgrounds and have knowledge and experience in agriculture and horticulture. The Ntinga members wish to reintroduce themselves into agriculture and develop skills in aquaculture with the hope of becoming fish farmers. The NMPC/Ntinga has gained a 5 year land lease agreement with the City of Cape Town which started 1 September 2014. Ntinga's members have identified an opportunity and interest in freshwater aquaculture which is still highly undeveloped in South Africa. Black communities make up the lowest share in the national sector of aquaculture and transformation in this sector is highly regarded.

The University of Stellenbosch's Aquaculture Division was approached to assist the Ntinga group with training and the setting up of a techno-operational framework and financial model for an aquaculture project. The University suggested that a recirculating aquaculture system be developed that would integrate aquaculture with horticulture otherwise known as aquaponic farming.

Aquaponics addresses the many challenges associated with urban farming and provides a diverse set of produce increasing urban food security.

The University suggests a four year roll out development plan which will start in 2015 and will be completed by 2018. In the initial start-up year NMPC will be trained through workshops hosted by the University of Stellenbosch so that they may gain skills and knowledge needed for aquaculture farming.

The first year, 2015, will focus on clearing the site, installing services, establishing a site office and erecting the first set of greenhouse tunnels. The co-operative will initially start growing vegetables on a small scale. A phased roll-out of aquaponics units will commence in 2015 what will start with basic greenhouse tunnels, a workshop, office and basic infrastructure, after that in 2016 the first of three aquaponic units (see figure 0.1 and 0.2 in appendix B) will be built with a unit being established each year. It is planned that through a process of four development phases, by 2018 three units would have been erected/built/installed.

Due to aquaculture being a more technical food production sector and given that many state funded development/empowerment projects fail or fail to remain profitable (Stoltz, 2010; Yeld, 2013; George, 2014), the Ntinga Multipurpose Co-operative project will focus on developing human capital in the form of experience, skills, knowledge and a support structure. Furthermore the project proposal and financial model is designed to start small and identify challenges in the 4 year roll-out phases.

The grant funding (no interest) will be used to develop the project and roll out the four phases between (2015-2018) to cover the total capital expenditure (CAPEX) costs of R3,450,000 and a total operational expenditure (OPEX) required are R250,000 which will be required from 2016.

The operation will be cash-flow positive within 6 months in 2016 and will break even after 2 years. Considered that this is grant funding the return on investment is not calculated.

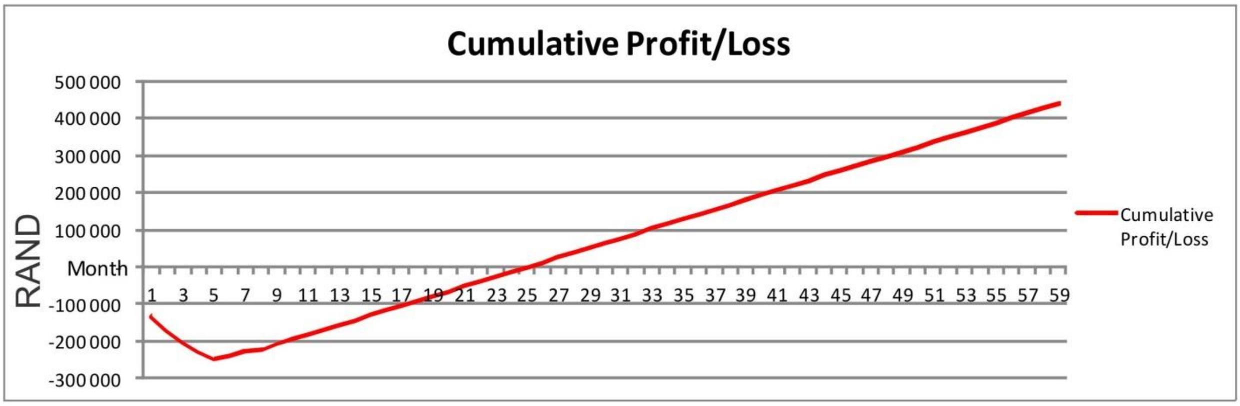

Figure 5.2: Cumulative profit/loss of NMPC (revenue vs. operational cost)

The products produced by NMPC will be sold through local markets like street vendors and local supermarkets. Supermarkets like Pick n Pay provide preference to local suppliers and have a programme to assist Broad Based Black Economic Empowerment (B-BBEE) suppliers (Ackerman, 2012).

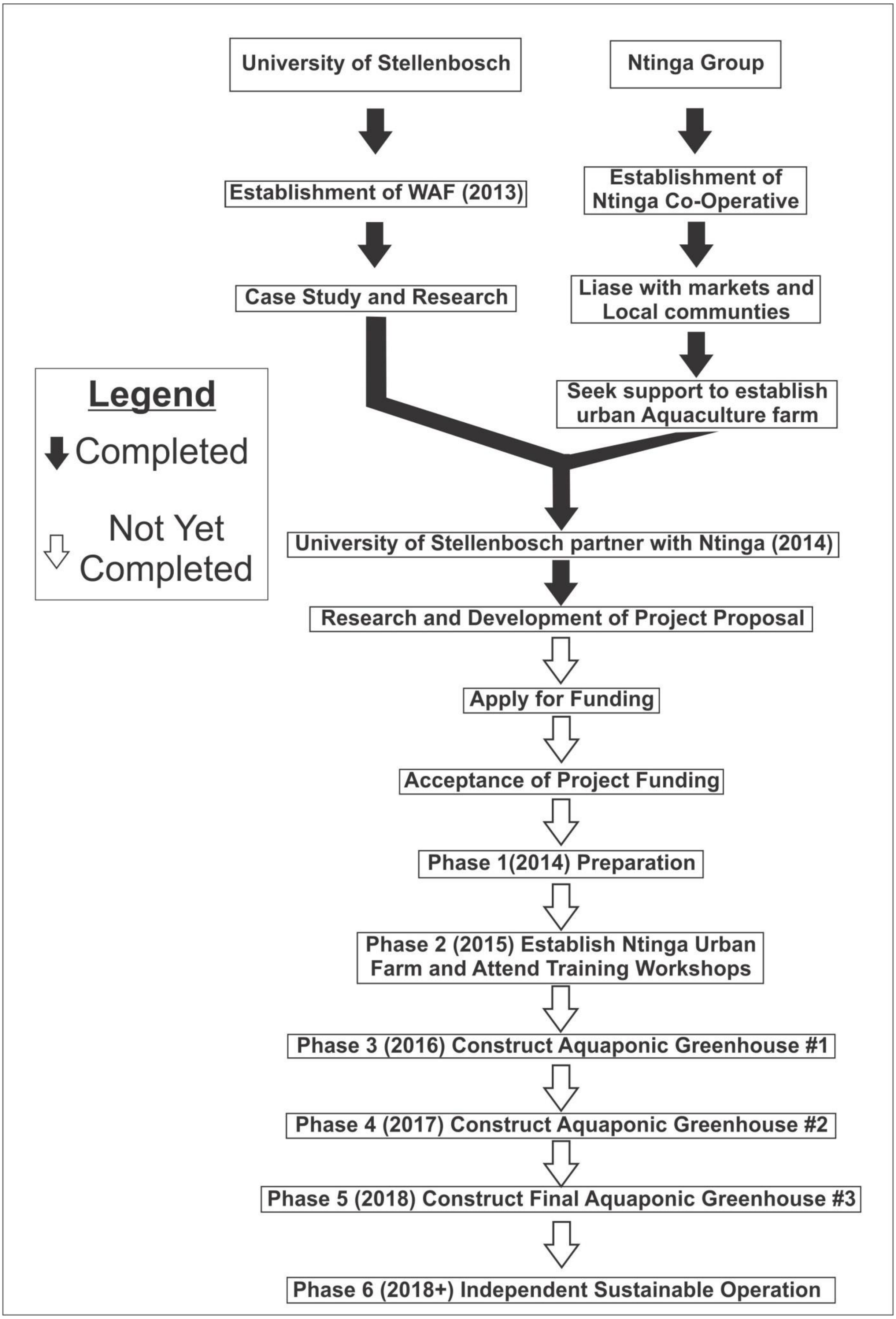

Figure 5.3: NMPC Project Time Frame.

5.4 Assumptions made for the project

In order to develop a feasible operation for Ntinga Multipurpose Co-operative, various scenarios were developed and tested against the assumed operational expenses relating to each Integrated Aquaculture Farming system.

The operational expenditure (OPEX) financial model does not claim to be a true reflection of the planned operational setup, but only acts as a guideline whereby different operational models could be tested based on an economy of scale.

Special note must be given to the following assumptions used in the financial models:

a) No current or historical financial statements were available for Ntinga Co-Operative Limited at the time of developing these financial models. No actual expenditure or revenue figures could be used for the calculations in the financial model.
b) With no clear indication of the secured and/or planned financial provision methods to be employed, the possible loan and interest repayment expenses have not been included in the current financial model.
c) All attempts have been made to provide for costing based on local supplier pricing, where available.

5.5 Problem Statement

5.5.1 Unemployment and poverty

The site chosen for the Ntinga project is located next to the Philippi Fresh Produce Market in the middle of the Cape Flats, surrounded by informal settlements (see figure 5.1) where poverty is widespread and food security is a major challenge (Battersby, 2011). It is estimated that more than 22% of Cape Town's citizens lived in poverty of which were mostly concentrated in the Cape Flats region. Poverty is defined as: "the inability of a person to meet their own basic needs and the needs of their dependents" (City of Cape Town, 2013b:2) .

Many people, especially vulnerable groups such as women, the elderly, people with disabilities and children face complex challenges and often find themselves in the poverty trap.

Jobs in Cape Town are scarce; most urban livelihoods are generated through the informal sector. Two thirds of African adults were declared unemployed with more than half of Cape Town's African households generating no income. The average wage labour income for those who were employed is R1463 per month. The average income for those without wage labour income is

R502 per month, which is below the poverty line of R560 per month (De Swardt, Puoane, Chopra, Du toit, 2005).

Poverty is primarily manifested in the ability to access food. It was found that in 2005, 39% of income expenditure amongst the poorest communities in Cape Town goes to food. Most of the indebted communities have stated that the primary reason to borrowing money was for basic survival: to buy food, pay for medical fees and to pay off other debts(De Swardt et al., 2005). The 2011 National Census reflected similar trends (StatsSA 2013)

5.5.2 Urban sprawl

It is predicted that Africa will become a predominantly urbanized population of 58% by 2050 (UN-Habitat, 2012). Our global population growth is forecasted to increase by 3 billion by 2050 (Brown, 2011). Feeding this future population of 9.2 billion people might be the biggest challenge we as a human race ever face. According to 2011 statistics, 62% South Africa's population live in urban areas (Central Intelligence Agency, 2014), which is expected to reach 80% by 2050 (Todes et al., 2010). Meeting the food security of South African citizens will therefore be an increasingly urban challenge and responsibility. Rising urban poverty is associated with many of the newly urbanizing populations that are cut off from their means of subsistence food production, which they relied on for food production in rural areas (Ziervogel & Frayne, 2011).

Philippi is located between the wealthy suburbs of Cape Town and the poorest African suburbs namely Khayelitsha and Nyanga. The poorly located African suburbs are a product of Apartheid social engineering and excessive urbanisation which created an overpopulated urban sprawl along the N2 highway and the False Bay coast. The population in the Cape Flats are deeply dependent on the City of Cape Town's economy and social grants(De Swardt et al., 2005).

Increased urbanisation and demand for housing have put enormous pressure on natural resources and urban farm land. South Africa's population is already 60% urbanised and it's expected to reach 80% by 2050 (Battersby, 2011) Cape Town faces increasing pressures and development challenges with regards to the rising poverty, housing shortage, and urban sprawl (Battersby, 2011).

5.5.3 Food security

The broadly accepted definition of food security termed by the FAO and the World Bank states: "Food security exists when all people, at all times, have physical and economic access to sufficient safe and nutritious food that meets their needs and food preferences for an active and healthy lifestyle " (FAO, 2008a). According to the FAO (2014) 14% of the world's population is undernourished, accounting for a third of all infant mortalities. According to Hasan (2012) between 2011-2013 about 842 million people suffered from chronic malnutrition. Despite an increased food production the undernourished population has increased by 9% to 12% globally since 1990 (Barrett, 2010).

Despite many citizens having access to food, many communities have access to food of sufficient calories but not sufficient nutritional value. Many South Africans suffer from malnutrition due to poor dietary diversity, and food insecurity has directly been correlated to an array of chronic illnesses in local communities (Frayne et al., 2009). According to Barrett (2010) it is estimated that more than a billion people lack sufficient dietary energy availability and more than two billion suffer from micronutrient (mineral and vitamin) deficiencies. This calls for action to provide access to more nutritiously balanced food.

In a dense urban environment such as the Cape Flats 80% of households are either moderately or severely food insecure. In Philippi and Kayelitsha less than 10% of households are food secure (Frayne et al., 2009; Battersby, 2011).Poverty impacts the food security status of an individual as well as of a family. Food insecurity is one of the main causes of poor health, more generally, and a driver of development-related challenges in children.

A Dietary Diversity study conducted by AFSUN in 2008 confirmed that the most commonly consumed foodstuffs were largely non-nutritive food, suggesting a diet deficient in vitamins, minerals and micronutrients (Battersby, 2011). Access to protein is generally restricted to plant based proteins. The households in the Cape Flats consume very little fish, where only 12% of Phillippi households and 16% of Kayelitsha households consume fish, mostly in the form of canned fish (Battersby, 2011).

According to Frayne et al. (2009), elements of an integrated food security strategy in a modern democratic city would consists of a food sector that is based on:

- A reduction of fossil fuel inputs;
- Maintaining and developing terrestrial and marine resources;
- Positive urbanisation;
- Improved livelihoods;
- Robust local food systems;
- Investment and development of local markets; and
- Mitigation of climate change.

5.5.4 Climate Change and Environmental Challenges

The fact that our climate is changing is backed by overwhelming evidence. Climate change has also been physically observed through the high frequency and severity of storms, temperature extremes and alternating precipitation patterns (Ziervogel & Frayne, 2011).

The effect of climate change on urban food security can be viewed according to the following categories direct and indirect:
a) Direct: Severe storms and temperature extremes and changes in rainfall patterns which impacts farmers and make it difficult for them to have successful crops.
b) Indirect: When climate change leads to irregular water supply that might lead to flooding or water scarcity.

Food production needs to cut down on its ecological footprint, currently one of the highest of all industries (Smith et al., 2007; Khan et al., 2009). The global rise in water scarcity is partially a consequence of an increased food demand from an growing population (Molden et al., 2007). The current food system in South Africa (and elsewhere produces food on farms that are located far from where the food is consumed. This results in long transportation lines with energy and other associated processes required, to keep food fresh. Farmers themselves are challenged by rising energy costs with those dependent on high energy-related inputs being most heavily impacted by volatile energy prices (Wakeford, 2006).

5.5.5 Human Capital

Farming with the new technologies that are available requires some basic training. With aquaculture it is important to be familiar with sound management practices and have some background of the biology, nutrition and of fish. Skills training without consideration of the farmers' socio-economic conditions will make it hard for the farmers to implement technical skills required in projects (El-Sayed, 2006). Many subsidized and government sponsored food producing projects have failed to operate sustainably due to several complex reason one of the main reasons are due to a lack of capacity and planning, (Stoltz, 2010; Yeld, 2013; George, 2014). For this reason research and development, and capacity-building in the field of recirculating aquaculture is seen as critical to improve understanding of it and avoid challenges that restrict the sectors' development.

Because aquaculture requires a high level scientific approach and management expertise (Stafford, 2013) it calls for research and capacity building to support sustainable development of the aquaculture in South Africa.

5.5.7 The Proposed Solution

It has been proposed by the University of Stellenbosch that integrating aquaculture with growing plants would provide a compact and efficient model for the needs of the Ntinga group. The model proposed is an integrated farming model which will be based primarily on recirculating indoor aquaculture and leafy crops. A secondary production stream will involve outdoor staple crop gardening.

The practice of integrating aquaculture with growing plants is called aquaponics. Aquaponics is a symbiotic agricultural practice that combines the practice of aquaculture and hydroponics in a recirculating system. The fish and food waste is used to supply the plants as a natural fertilizer, when plants absorb the nutrients it also acts as a filter by purifying the water removing it of nutrients to be used again by the fish as demonstrated in figure 5.4 (Rakocy, et al., 2006)

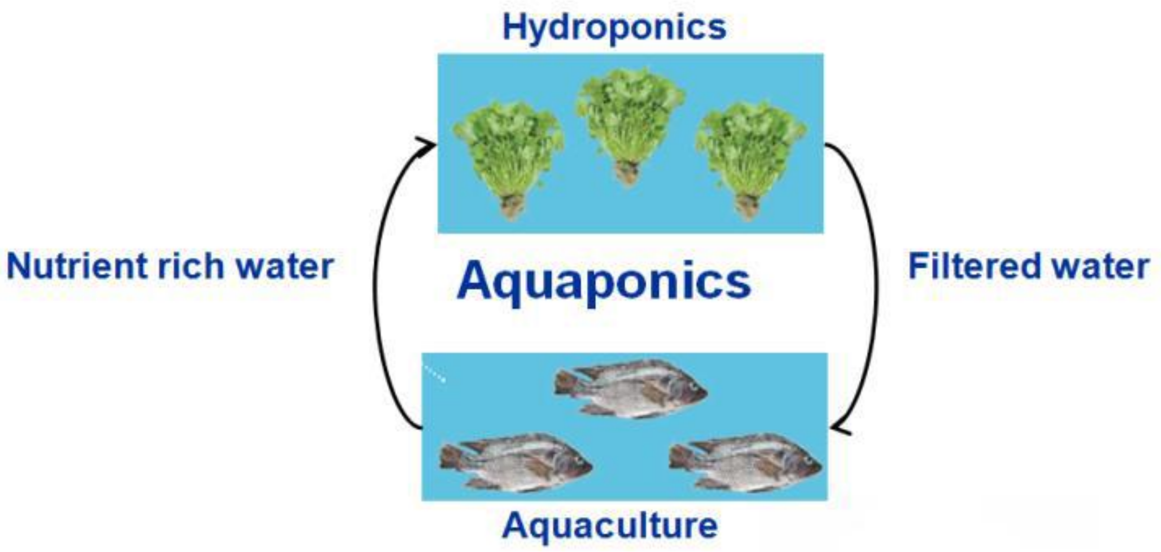

Figure 5.4: Illustration of an Aquaponic Recirculating System (Rakocy, et al., 2006)

Aquaponics is the chosen technology proposed because of the following factors:

- Addressing food security is essential; access to food is not only a constitutional right but also forms part of the City of Cape Town's developmental aims of access to adequate, nutritious, hygienic and culturally appropriate food.
- The integrated aquaculture model supplies a variety of nutrients which are essential for healthy development and well-being, namely; high quality protein, carbohydrates, fats, minerals and vitamins.
- The integrated aquaculture model is highly resource efficient through the process of water recirculation and the breaking down of fish waste into soluble nutrient fertilizer required by plants.
- The only solid waste that is produced is composed as a high value nutrient source for greenhouse tunnel gardening.
- Using the advantage of being an urban food producer and supplying food locally, close to consumers the distance travelled to deliver food will be reduced.
- The farming model will create direct jobs through the construction and development process, income and food security for the NMPC owners and employees (hired) who will have positive spin-offs for their families and surrounding community.
- The integrated aquaculture model will produce high volumes of food but will require limited surface area. Production will be resistant to adverse weather and water restrictions because the technology recirculates water and is contained in protective greenhouses.

- Large variations in seasonal temperature are one of the main challenges to aquaculture. This challenge can make it difficult to achieve sustainable results because fish like the Tilapia generally require warm water throughout the year.

The University of Stellenbosch will assist with the training of the Ntinga group (owners) through a series of workshops to help them understand the fundamental principles of aquaculture and greenhouse management.

The City of Cape Town promulgated the Food Gardens Policy in Support of Poverty Alleviation and Reduction in December 2013. This policy commits the City to addressing poverty and improving the livelihoods of the poor, marginalised and vulnerable communities of the City of Cape Town. The City aims to coordinate efforts and to work with different spheres of government to develop sustainable livelihood programmes and projects. Projects identified are urban food garden initiatives that are sustainable which may aid in the food insecure in low income communities (City of Cape Town, 2013b).

5.6 Capital Expenses

Summary of each Phase’s capital expenditure needs below:

	Phase Required	**CAPEX Required**
	Phase 0 - 2014 (Planning)	
	Phase 1 – 2015	R 450 000
	Phase 2 – (B – 2016)	R 950 000
	Phase 3 – (C – 2017)	R 1 125 000
	Phase 4 – (D – 2018)	R 925 000
	TOTAL CAPEX	**R 3 450 000**

Table 5.1: CAPEX required for NMPC

A more detailed financial plan is attached in Appendix B.

Phase 0 will require no funding as this is a planning phase.

Phase 1 – 2015

The capital amount indicated in the table 5.1 above basically includes the following elements:

1. Fencing and Deforestation
2. Site Offices with parking area
3. Delivery vehicle x 1
4. Standard greenhouse tunnels x 4

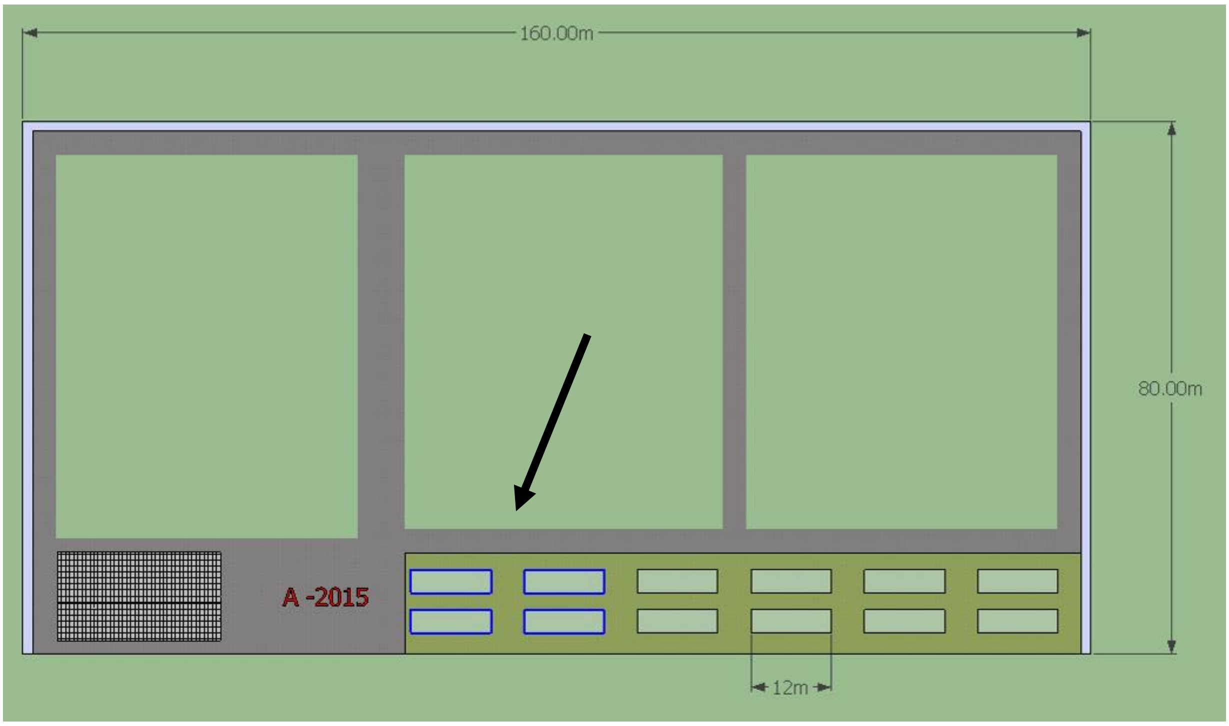

Figure 5.5: Outlay of Phase 2 development in 2016.

Although only 4 greenhouse tunnels have been included in the estimates, the layout design made use of all available space – allowing for a total of 12 tunnels to be erected on the available space.

Phase 2: (B – 2016)

The capital expenditure indicated for table 5.1 above, makes provision for:

1. One Additional borehole
2. Crop greenhouse tunnels x 5 (30m long) with aquaponic grow beds
3. Construction of Aquaculture greenhouse system.
4. All other equipment, labour and tools required

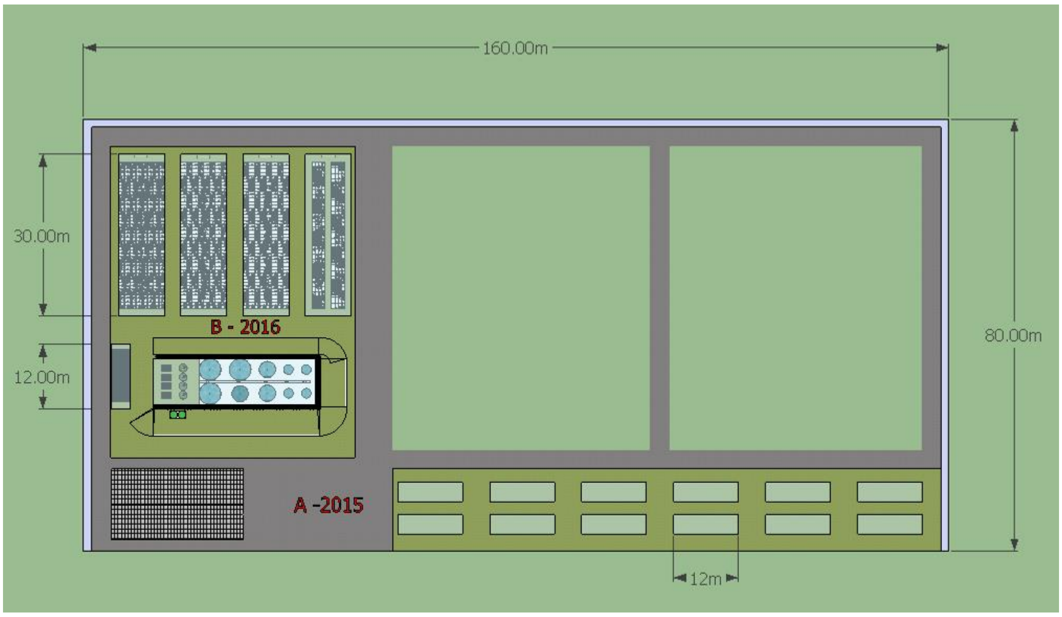

Figure 5.6: Outlay of Phase 3 development in 2017.

Phase 3: (C – 2017)

This phase is a duplication of the previous phase, basically multiplying the production and facilities. The only differences involved are:

- No additional borehole needs to be drilled again
- A small refrigerated delivery truck in included in this phase. Deliveries during this phase and further become too large for a light delivery vehicle to handle.

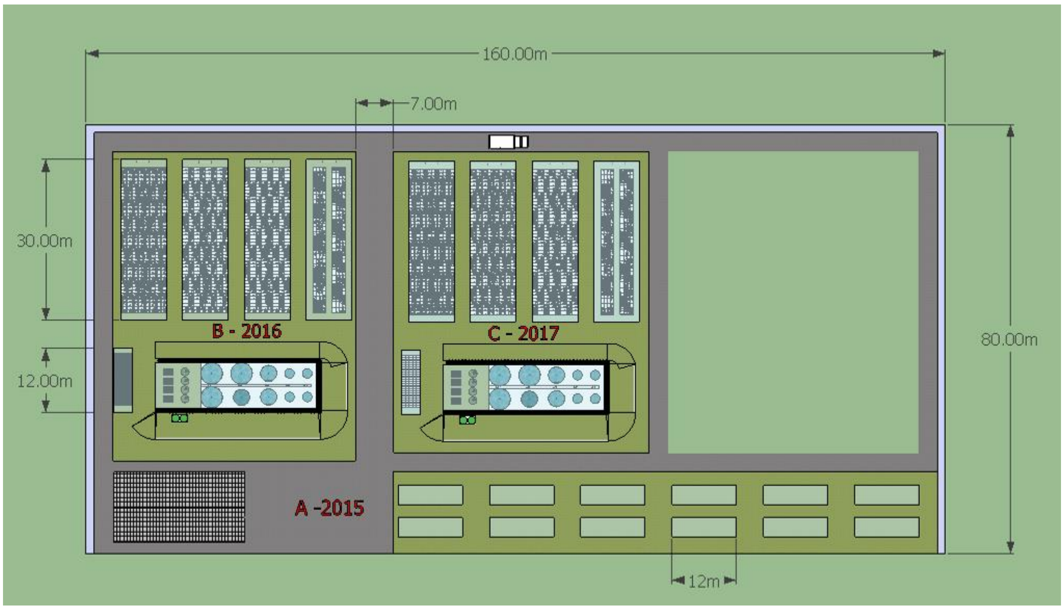

Figure 5.7: Outlay of Phase 3 development in 2017.

PHASE 4: (D-2018)

Capital expenditure estimations indicated that this would be the most affordable phase as the phases A,B,C are duplicated, mainly because of the following facts:

- This is once again just a duplication of the previous phase
- No additional boreholes are foreseen
- No additional vehicle purchases are foreseen

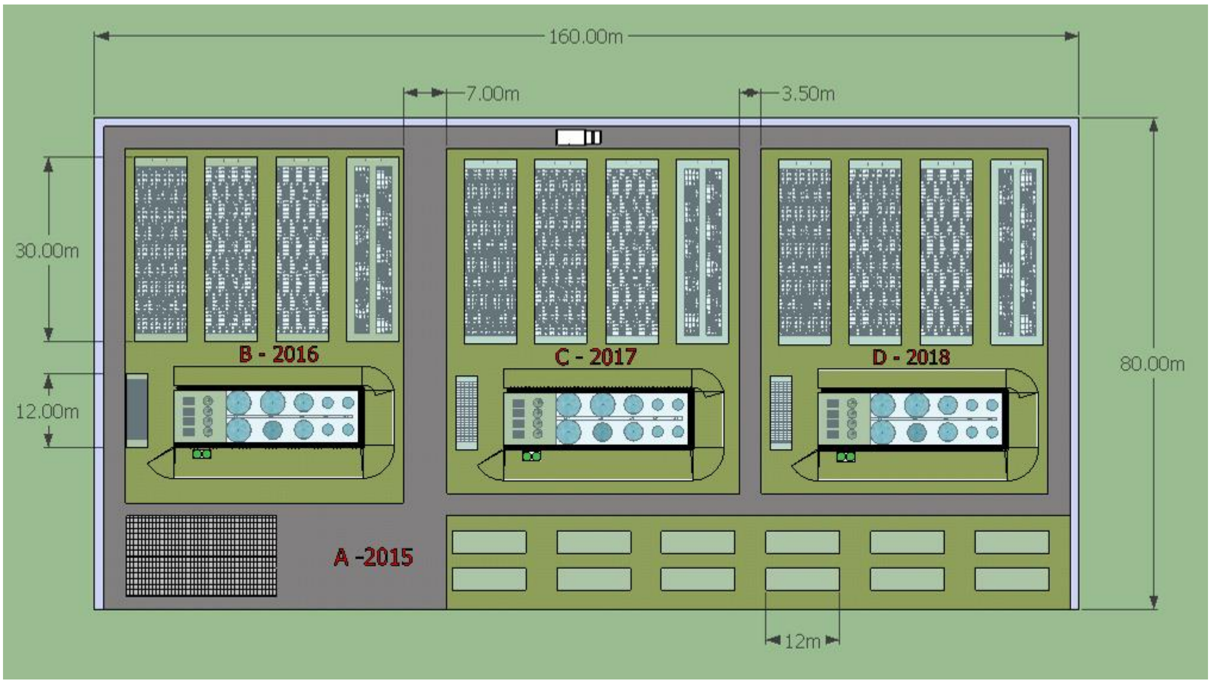

Figure 5.8: Outlay of Phase 3-(D) development in 2018.

Strengths	Weaknesses
• Highly resource efficient food production. • Self-cleaning and recirculation of water • Can produce fish and plants together • Recirculating technology allows for systems to be placed anywhere, independent from high water use.	• System design requires professional help or extensive self-research. • Managing aquaculture and hydroponics can be technical and difficult • Aquaponic systems require constant hands on management. • Aquaculture markets underdeveloped in South Africa.
Opportunities	**Threats**
• Diversity of produce • Double stream of income (fish and produce) • Using faster growing Nile tilapia fish • Controlled environment farming is more resilient to external factors. • Largely undeveloped aquaculture industry • Supporting policies by government do develop aquaculture. • Aquaponics complying with the new NEMBA act which regulate biodiversity control.	• A high risk venture • Climate • High energy use in winter • High capital & operation costs • Market of warm water commercial fish like Tilapia in South Africa not yet established.

Table 5.2: SWOT analysis of Aquaponic systems in South Africa.

5.7 Growth and market structure

In order to maintain a viable business and to achieve targets to improve food security and community upliftment the NMPC will produce fish and fresh produce for local supermarkets, small food markets and street vendors that will ensure that food reaches the wider community.

Secondary fresh produce which will be grown outside the greenhouses will also be sold through the same channels as mentioned above.

The funding for this project can be regarded as a grant or investment. By which a grant will require no return to the financiers and an investment would require a return on investment. The financial model will be attached in the Appendix B.

The growth and marketing structure will be done systematically and as production volumes increase over time higher and more sophisticated markets will be approached. A new born baby first needs to crawl before it can learn to walk and run. This concept of growth and expansion will also be followed in the marketing strategy. With the first tunnel in phase one the co-operative will produce products to support their own households and market the balance to the local community and the Phillippi Fresh Produce Market. In phase 2 the co-operative will supply products regionally and in phase 3 to the wider City of Cape Town if possible and needed.
The Operation and Maintenance (O&M) information is attached in the Appendix B.

5.8 Approach and Methodology

The size of operations is determined according to the total biomass (total weight) fish produced per month, which is the determining factor for the amount of vegetable crops that can be produced. The literature and industry uses lettuce as the benchmark crop when determining the design perimeters of a new operation (Kempen, 2014). Lettuce in general is a lower value crop, and considering other suitable vegetables to be used in conjunction with lettuce should provide for significant financial gains. The current model is based on producing lettuce crops and Nile Tilapia fish. This is however standards of development, the NMPC may produce crops which have higher nutrient values such as spinach and watercress. Note that lettuce will be fully grown after 1 month (4 weeks) after planting them, thus it will be in production within the first month.

During the early planning stages of the project, Mr. Henk Stander of the Aquaculture Division of Stellenbosch University advised that the project should be sized at around 600 Kg product Tilapia fish per month. The basic approach used in determining a feasible size of operation began with a small scale design whereby it was attempted to minimise the initial capital expenditure. Initial studies were conducted on a production of 100kg Tilapia fish per month, but soon proved to be uneconomical, even after 5 years of operation.

A production of 400kg Tilapia per month seems to be the minimum efficient scale of operations in order to turn cash-flow positive, when operating on full production capacity. However the risk in using the 400kg production model is that even the smallest negative offset in operational expenses could turn the project in a negative cash flow situation.

It is therefore recommended that the financial model be based on a production of at least a 600kg Tilapia per month in order to provide for a lower risk project proposal.

	Unit of measure	100 Kg per Month	400 Kg per Month	600 Kg per Month
Production Figures				
Fish sales	Kg/Month	100	400	600
	#/Month	125	500	750
Crops sales (lettuce)	Kg/Month	800	3 200	4 800
	#/Month	4 000	16 000	24 000
Estimated Operational Expenditure (Excluding loan repayment, interest and tax)				
Operational Expenses - Fish	R/Month	R 3 500	R 10 500	R 15 000
Operational Expenses - Crops	R/Month	R 1 500	R 5 000	R 7 000
Operational Expenses - Overheads	R/Month	R 21 000	R 23 000	R 24 000
Operational Expenses - Combined	R/Month	R 26 000	R 38 500	R 46 000
Estimated Revenue (Excluding loan repayment, interest and tax)				
Revenue – Fish	R/Month	R 3 500	R 14 000	R 21 000
Revenue – Crops	R/Month	R 6 400	R 25 500	R 38 000
Revenue – Combined	R/Month	R 10 000	R 39 500	R 59 000
Net Profit Estimation				
Net Profit – Combined	R/Month	- R 16 000	R 1 000	R 13 000

Table 5.3: Comparison of the three production models.

The current model is based on buying fingerlings starting with mature fish which also justifies why fish could be sold after 3 months. It will take too long and unprofitable for fish to grow out and get in production after 10 months. Initial estimates used in the Ntinga 600kg model were based on assumptions that all fish will be purchased from fingerling size. The main concern with the initial model is that fish sales will then only come into play in the revenue stream at Month 11, after which the fingerlings have been grown to marketable size.

Chapter 6 - Conclusion

Despommier's statement on page xiv marks the point of departure for the arguments in this thesis in which we are to rethink and approach our food production alternatively with a realistic view of the rising challenges we face.

With the rapidly urbanizing population there will be an increased pressure on cities to feed its populations and maintain a nutritious healthy wellbeing. To feed the rising population whilst making room for development will put pressure on space and quality of arable land resources. Methods need to be explored to deal with the challenges the changing climate and demand put on our freshwater reserves which are currently being mainly used for agricultural irrigation.

Having enough to eat is not enough for humans to maintain a healthy wellbeing, having access to available nutritious food such as fish is seen as a first step to a sustainable way of maintaining a healthy lifestyle. South Africa's aquaculture is heavily undeveloped, its development holds the potential to contribute to create jobs, support the economy and to support food security.

The NMPC project proposal was compiled with an approach to support food security in Philippi an area of widespread urban malnutrition and poverty. The study explored the feasibility of using freshwater aquaculture as method to produce high quality food.

Governing institutions supports aquaculture development in which they aim to fill the national backlog of aquaculture development and to create jobs, and support food security.

Aquaponics was identified as an effective approach to use the newly introduced Nile tilapia fish species; it is recommended to use aquaponic technology by which it complies with biosecurity and environmental regulations and several challenges that face aquaculture development. It was also identified that aquaponics is a highly efficient food production method which produces a diversity of nutritious fish and produce with very little water inputs, required no arable land and had a minimal environmental footprint as its waste is recycled.

It was identified that agricultural projects often fail due to a lack of planning, training and knowledge. In regards to aquaponics which requires scientific high level management skills it calls for training and skills development. A technical study was conducted to compile the fundamental production and management principles of aquaculture and hydroponic technologies which is required to approach aquaponics.

A practical empirical case study was carried out to identify design flaws, component analyses and the daily management procedures and challenges of aquaponic systems.

A techno-financial model was constructed that made up the project proposal for this study. The project proposal was laid out in four phases over the years 2014- 2018. It was found that this aquaponics project is viable through grant funding and that it would be cash flow positive within 6 months and will cover OPEX funding within two years. The project is set to be self-sufficient and independent by 2018.

It was found that aquaponics is a highly effective food production technology which be easily incorporated with the large scale aquaculture development in South Africa. It poses the potential to be located in remote places such as cities in which it can be used as an effective method to produce highly nutritious food to combat the spread of food insecurity and malnutrition.

Limiting factors

The factors that limited this study had been to scientifically determine results over a long period of time. This study has been limited to only basic hands on experience and observation. The study had been limited to the use of only 60kg of Mozambique Tilapia which limited the study to little amounts of plants.

The study has also been limited to conducting no water quality monitoring which is due to a lack of monitoring equipment which had to be imported.

The study proved outdoor aquaponics to be limited to only warmer months which call for closed environment aquaponic systems that are able to efficiently maintain heated water in the system. The study proved that aquaponics should be approached with the climate in mind, most regions of South Africa doesn't have favourable temperature zones for popular commercial warm water or cold water fish species which restricts the development of the technology. Aquaponics will be relevant for regions with very stable annual temperature zones such as regions in Kwa-Zulu

Natal, Mpumalanga, the Eastern Cape and the Limpopo Province and it will be relevant to regions with constant cool temperature zones such as mountainous regions of the Drakensberg mountain range and the Cape Fold Mountains.

A great deal surrounds the economic feasibility of aquaponics; this has to be investigated through a project proposal and business model. The issues discussed in Chapters 3 and 4 have to be incorporated in the approach for an effective project.

Further study recommendations

The reasons stated in Chapter 1.3 can be addressed by aquaponic technology. It has been argued in this study that exotic fish species can be used in aquaponic systems because it is a closed system and pose no risk to biosecurity. Considering South Africa's climate and limited seasons to farm fish, further research is to be done to explore alternative technology and energy efficient methods to produce freshwater aquaculture year round. This also calls for a further study as to explore methods to educate the public on aquaculture to generate skills and knowledge.

Further studies can also be done on identifying the performance, waste management and water quality of polyculture in aquaponic systems as to include freshwater bivalves, and bottom feeder species.

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Appendices

Appendix A : General Information

52

B-1 World aquaculture production by species groups
Production mondiale de l'aquaculture par groupes d'espèces
Producción mundial de acuicultura por grupos de especies

Q = t
V = USD 1 000

	Species group Groupes d' espèces Grupos de especies		2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
	Carps, barbels and other cyprinids	Q	15 635 801	16 890 099	17 754 025	18 523 347	18 956 827	20 683 156	22 231 093	23 437 048	24 066 383	25 404 797
11	Carpes, barbeaux et autres cyprinidés	V	14 008 654	15 985 142	16 370 596	17 700 902	23 184 524	27 248 997	29 403 839	32 621 163	34 211 500	36 756 235
	Carpas, barbos y otros ciprínidos											
	Tilapias and other cichlids	Q	1 587 148	1 795 224	1 991 569	2 234 006	2 553 969	2 826 297	3 108 626	3 496 165	3 975 260	4 507 002
12	Tilapias et autres cichlidés	V	1 853 906	2 053 224	2 260 729	2 645 482	3 654 577	4 128 469	4 911 247	5 680 410	6 655 196	7 656 257
	Tilapias y otros cíclidos											
	Miscellaneous freshwater fishes	Q	3 098 666	3 518 457	3 927 595	4 528 907	5 115 120	5 522 019	5 315 289	5 956 006	6 522 377	7 505 815
13	Poissons d'eau douce divers	V	4 633 699	5 120 560	5 813 446	6 945 006	9 169 409	10 225 386	9 977 468	11 339 878	13 046 336	14 675 852
	Peces de agua dulce diversos											
	Sturgeons, paddlefishes	Q	13 398	14 006	17 955	19 224	25 873	26 413	33 824	40 828	51 817	64 809
21	Esturgeons, spatules	V	63 121	68 061	78 945	79 658	105 047	152 951	160 097	175 179	228 947	271 027
	Esturiones, sollos											
	River eels	Q	209 963	223 672	217 185	238 828	273 476	265 111	275 014	271 094	253 773	241 285
22	Anguilles	V	690 782	740 090	969 803	1 044 370	1 270 481	1 324 795	1 384 849	1 528 033	1 781 455	1 372 849
	Anguilas											
	Salmons, trouts, smelts	Q	1 876 725	1 986 934	2 003 534	2 122 152	2 238 113	2 313 006	2 456 626	2 422 494	2 777 370	3 227 629
23	Saumons, truites, éperlans	V	5 651 436	6 685 469	7 742 280	9 845 889	10 727 279	10 739 451	11 457 569	12 674 813	15 047 038	15 276 134
	Salmones, truchas, eperlanos											
	Shads	Q	206	56	708	2 700	1 292	397	34	...	136	120
24	Aloses	V	206	56	5 749	14 120	3 721	2 574	252	...	1 077	843
	Sábalos											
	Miscellaneous diadromous fishes	Q	580 781	602 663	626 255	617 919	702 316	719 822	766 954	875 664	960 356	1 018 665
25	Poissons diadromes divers	V	578 561	782 494	700 395	746 659	904 781	1 110 510	1 218 281	1 493 396	1 867 410	2 049 505
	Peces diádromos diversos											
	Flounders, halibuts, soles	Q	83 453	101 742	125 536	118 089	128 799	148 382	168 479	147 754	178 914	181 813
31	Flets, flétans, soles	V	536 881	697 558	809 414	948 066	978 332	994 851	1 096 473	1 095 342	1 177 954	1 132 465
	Platijas, halibuts, lenguados											
	Cods, hakes, haddocks	Q	2 630	3 881	8 193	13 284	13 722	21 387	22 729	22 558	16 150	10 926
32	Morues, merlus, églefins	V	8 845	13 283	27 387	50 707	55 089	83 831	64 764	62 830	50 584	38 957
	Bacalaos, merluzas, eglefinos											
	Miscellaneous coastal fishes	Q	695 237	709 898	794 080	891 461	973 784	943 429	953 984	951 820	984 922	1 087 528
33	Poissons côtiers divers	V	2 257 199	2 360 379	2 677 176	2 933 305	3 385 845	3 621 893	3 512 171	3 778 706	4 319 020	4 545 165
	Peces costeros diversos											
	Miscellaneous demersal fishes	Q	23 938	19 708	21 636	28 013	35 979	33 255	33 290	21 198	17 645	23 290
34	Poissons démersaux divers	V	140 313	154 125	197 587	202 970	218 113	195 322	198 327	173 863	140 850	135 617
	Peces demersales diversos											
	Tunas, bonitos, billfishes	Q	4 786	13 136	10 509	14 720	11 284	12 796	11 926	9 412	9 389	16 887
36	Thons, pélamides, marlins	V	81 871	193 708	114 546	158 167	143 866	170 519	142 750	116 127	151 846	131 473
	Atunes, bonitos, agujas											
	Miscellaneous pelagic fishes	Q	193 422	185 752	197 257	194 878	243 762	243 850	280 152	282 986	322 056	334 768
37	Poissons pélagiques divers	V	1 140 877	1 086 000	1 038 382	1 093 850	1 209 928	1 369 474	1 604 624	1 784 645	2 015 369	2 145 968
	Peces pelágicos diversos											
	Marine fishes not identified	Q	223 559	241 505	283 984	383 033	329 293	548 027	479 081	404 518	517 054	525 821
39	Poissons marins non identifiés	V	270 291	262 598	314 311	426 268	579 289	855 616	735 467	898 039	1 203 713	1 310 389
	Peces marinos no identificados											
	Freshwater crustaceans	Q	784 816	845 978	913 638	954 603	1 271 584	1 373 886	1 555 211	1 692 215	1 665 055	1 827 313
41	Crustacés d'eau douce	V	3 023 974	3 571 090	3 898 226	4 220 785	6 599 842	7 673 998	8 676 159	9 491 432	9 560 988	10 481 207
	Crustáceos de agua dulce											
	Crabs, sea-spiders	Q	167 533	178 838	195 995	198 243	231 070	240 787	246 534	254 378	270 087	289 949
42	Crabes, araignées de mer	V	414 904	454 031	549 773	580 878	648 110	747 875	767 332	807 637	861 036	932 841
	Cangrejos, centollas											
	Lobsters, spiny-rock lobsters	Q	35	39	29	35	70	1 092	1 412	1 611	1 805	2 035
43	Homards, langoustes	V	502	660	527	710	1 863	11 251	14 140	16 285	18 821	20 967
	Bogavantes, langostas											
	Shrimps, prawns	Q	2 050 627	2 364 536	2 667 949	3 111 748	3 295 031	3 400 216	3 531 954	3 778 856	4 185 086	4 327 520
45	Crevettes	V	8 179 513	9 360 737	10 495 437	12 255 108	13 260 577	14 431 069	14 870 657	16 654 797	19 119 398	19 428 752
	Gambas, camarones											
	Miscellaneous marine crustaceans	Q	3	21	14	30	30	16	...	...	...	...
47	Crustacés marins divers	V	37	395	461	932	945	629	...	...	...	...
	Crustáceos marinos diversos											
	Freshwater molluscs	Q	112 985	125 212	127 107	135 124	139 024	153 471	155 892	164 325	175 138	175 421
51	Mollusques d'eau douce	V	63 595	79 514	73 408	81 677	109 432	138 101	133 978	143 241	161 973	158 131
	Moluscos de agua dulce											
	Abalones, winkles, conchs	Q	205 560	251 549	291 985	320 356	374 736	359 418	354 382	385 340	394 978	426 434
52	Ormeaux, bigorneaux, strombes	V	231 545	296 906	374 327	444 184	546 234	619 341	672 697	779 185	884 457	1 005 942
	Orejas de mar, bígaros, estrombos											
	Oysters	Q	4 016 389	4 142 740	4 155 840	4 260 119	4 402 914	4 147 512	4 311 363	4 488 751	4 505 294	4 741 893
53	Huîtres	V	2 470 739	2 614 098	2 859 899	2 937 807	2 962 959	3 290 607	3 350 964	3 601 119	3 830 822	3 898 798
	Ostras											
	Mussels	Q	1 623 298	1 669 844	1 718 513	1 771 475	1 598 065	1 587 987	1 727 947	1 805 366	1 877 338	1 828 845
54	Moules	V	971 119	907 048	1 044 899	1 220 477	1 622 336	1 629 838	1 508 181	1 568 192	2 292 779	2 053 460
	Mejillones											
	Scallops, pectens	Q	1 102 063	1 052 561	1 146 909	1 261 693	1 464 172	1 410 899	1 583 614	1 727 105	1 519 613	1 651 353
55	Coquilles St-Jacques	V	1 443 869	1 599 802	1 836 087	1 946 147	2 221 876	2 344 581	2 499 518	3 017 879	2 830 969	2 849 265
	Vieiras											

Table 0.1: World Aquaculture Production by Species Group (FAO, 2012b)

B-1 World aquaculture production by species groups
Production mondiale de l'aquaculture par groupes d'espèces
Producción mundial de acuicultura por grupos de especies

Q = t
V = USD 1 000

	Species group Groupes d' espèces Grupos de especies		2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
56	Clams, cockles, arkshells Clams, coques, arches Almejas, berberechos, arcas	Q	3 372 451	3 634 661	3 677 841	3 798 412	4 202 069	4 364 979	4 451 924	4 887 558	4 926 534	4 999 204
		V	3 785 397	2 943 084	3 410 267	3 668 861	3 973 480	4 257 929	4 348 272	4 767 663	4 915 551	4 951 966
57	Squids, cuttlefishes, octopuses Encornets, seiches, poulpes Calamares, jibias, pulpos	Q	8	12	16	11	27	30	15	10	3	5
		V	32	48	64	44	108	254	84	62	23	25
58	Miscellaneous marine molluscs Mollusques marins divers Moluscos marinos diversos	Q	918 025	959 459	995 028	1 124 933	849 829	982 915	927 114	697 500	1 055 472	1 347 582
		V	486 524	537 148	584 538	662 862	525 626	639 750	604 283	477 700	696 327	939 442
71	Frogs and other amphibians Grenouilles et autres amphibies Ranas y otros anfibios	Q	70 718	67 796	74 541	75 521	80 638	85 300	95 938	82 941	111 774	116 991
		V	256 825	243 557	272 891	285 848	381 659	434 181	488 239	425 423	508 056	534 588
72	Turtles Tortues Tortugas	Q	139 098	155 371	174 965	182 971	212 907	229 308	258 249	295 536	320 388	368 466
		V	529 739	591 991	670 948	717 968	1 049 868	1 208 797	1 353 945	1 550 562	1 687 762	1 936 616
74	Sea-squirts and other tunicates Ascidiens et autres tuniciers Ascidias y otros tunicados	Q	15 602	21 442	17 958	16 931	19 487	18 605	18 145	16 636	12 369	9 641
		V	12 339	17 824	22 681	21 763	27 778	26 730	26 668	29 414	20 842	16 825
76	Sea-urchins and other echinoderms Oursins et autres échinodermes Erizos de mar y otros equinodermos	Q	37 482	53 258	62 953	74 918	85 140	96 000	109 053	137 160	145 081	177 597
		V	112 530	159 903	208 301	254 657	264 692	333 925	378 116	481 442	506 751	621 764
77	Miscellaneous aquatic invertebrates Invertébrés aquatiques divers Invertebrados acuáticos diversos	Q	69 293	78 673	95 843	73 896	109 547	188 432	251 642	282 583	191 906	191 848
		V	136 094	158 377	207 463	166 885	228 259	433 753	532 548	570 267	411 794	402 183
91	Brown seaweeds Algues brunes Algas pardas	Q	5 983 337	6 402 367	6 926 355	6 644 891	6 536 197	6 628 214	6 726 316	6 787 493	7 153 019	7 955 093
		V	1 177 589	1 352 748	1 428 757	1 292 315	1 223 576	1 121 102	1 087 150	983 675	1 065 807	1 353 161
92	Red seaweeds Algues rouges Algas rojas	Q	3 125 513	3 963 305	4 682 490	5 292 961	6 071 748	6 700 174	8 043 083	8 977 849	10 841 808	12 906 177
		V	1 226 162	1 548 185	1 699 933	1 782 844	2 002 990	2 023 435	2 654 615	3 186 312	3 205 885	3 797 775
93	Green seaweeds Algues vertes Algas verdes	Q	7 952	18 636	12 266	18 329	16 676	26 133	22 368	21 546	21 540	19 900
		V	3 608	12 567	6 655	11 451	8 137	17 226	12 966	12 835	14 879	13 979
94	Miscellaneous aquatic plants Plantes aquatiques diverses Diversas plantas acuáticas	Q	2 284 949	2 280 334	1 897 835	2 135 094	2 369 008	2 524 411	2 564 840	3 222 779	2 962 566	2 895 279
		V	945 072	936 505	781 443	898 693	1 027 972	1 216 725	1 210 022	1 508 024	1 229 294	1 204 724

Table 0.2: World Aquaculture Production by Species Groups (FAO, 2012b)

Appendix B : Project proposal

Issues	Local (Philippi)	Regional (Western Cape	National (South Africa)
INPUTS			
Production of locally produced fish feed	+Low cost fish feed improved production costs	- Effect on wild fish stock used to produce fishmeal +Effect on fisheries communities and communities involved in feed production	- Effect on wild fish stock used to produce fishmeal
Labour	+Job opportunities and improved livelihoods	+Job opportunities and improved livelihoods	
Infrastructure	+New available Infrastructure available of Experimental Farm		
RESOURCE USE			
Water	-Use of water for constant flushing and cleaning +Efficient water use due to recirculation of water +No waste produced and water pollution caused	+Efficient water use due to recirculation of water +No competition with other freshwater water resources +No waste produced and water pollution caused	
Land use/ Ecosystem	+Efficient land space use +Water is recirculated in closed loop +No competition with local freshwater resources +Fish species pose no threat to external ecosystem and biodiversity.	+Fish species pose no threat to external ecosystem and biodiversity. +No competition with regional freshwater resources	
Energy	- Use of energy to power compressors, pumps and heat pump. - No aquaculture room insulation + Insulated pipes and fish tanks +Pump energy is efficiently used by gravity flow design +Use of self-draining bell		

	siphon grow bed drains which require no aerators		
OUTPUTS			
Biomass	+ Potential biomass production (fish and plants) for hunger alleviation and food security	+ Potential biomass production (fish and plants) for hunger alleviation and food security	+ Potential biomass production (fish and plants) for hunger alleviation and food security -Possible competition with other common food markets.
Income	+ Alleviation of poverty with income. +Economic growth in direct area.	+Economic support to local markets and value adding chain	+Alleviation of poverty for migrant workers sending back financial support to homelands.

Table 0.3: Ecological impact of project

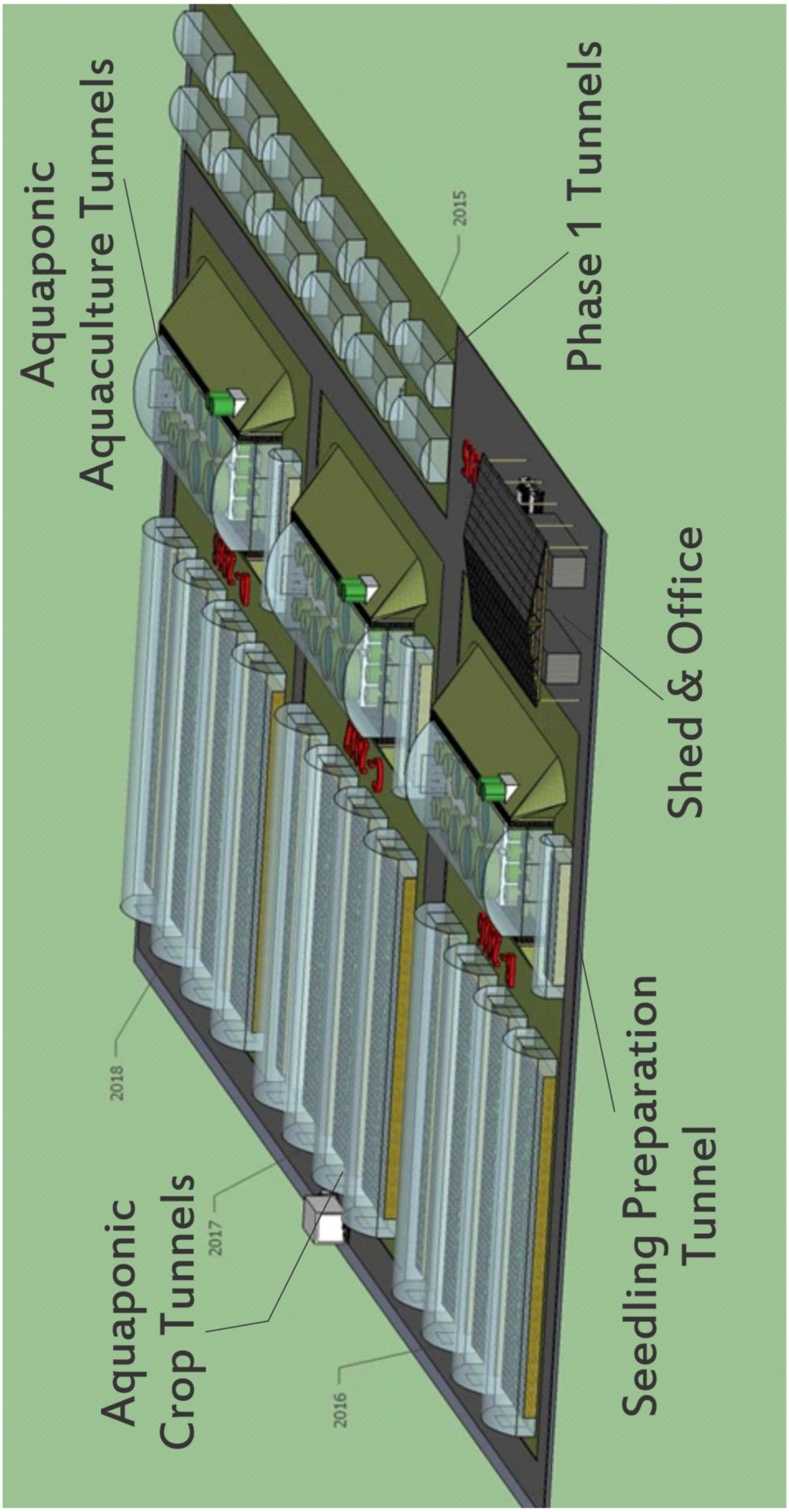

Figure 0.1: Site layout of NMPC

Figure 0.2: Top view of NMPC site

Calculations (Fish to plants)

1	2	3	4	5	6	7	8	9	10		Tilapia harvest cycle (10 months)
30	30	30	30	30	30	30	30	30	30		Ave days per month
1	5	20	50	100	165	250	350	475	625	Start	Fish weight started in (g)
5	20	50	100	165	250	350	475	625	800	End	Fish weight end in (g)
11	42	60	120	99	150	147	200	244	312	1 384	Fish food /month/stage/fish in (g)
1 005	940	887	844	812	788	773	765	758	750	8 321	Total amount of fish at any given time (mortality rate: large fish@1% /m) (g)
5 027	18 794	44 326	84 430	133 951	197 045	270 454	363 411	473 438	**600 000**	2 190 875	Total desired production of fish/month in (g)
											(Industry average feed @ 2% of body mass)
10 558	39 468	53 191	101 316	80 371	118 227	113 591	152 632	184 641	234 000	1 087 993	Total Feed/month in (g)
										36 266	Total feed/day in (g)
0.14	0.54	1.27	2.41	3.83	5.63	7.73	10.38	13.53	17.14	62.60	volume required (m^3)
0.20	0.38	0.58	0.80	1.01	1.22	1.43	1.66	1.89	2.13		Radius of vertical tank required @ stocking density kg/m3
0.39	0.76	1.16	1.60	2.02	2.44	2.86	3.32	3.79	4.27		Diameter of each reservoir @ 1.2m height (m)
1.80	1.80	1.80	1.80	3.00	3.00	3.00	4.00	4.00	4.00		Diameter of each reservor @ 1.2 m rounded off to given supplier standard sizes (m)
2.29	2.29	2.29	2.29	6.36	6.36	6.36	11.30	11.30	11.30		Resulting volume of water per tank (m3)
2.20	8.21	19.36	36.88	21.07	30.99	42.53	32.15	41.88	53.08		Resulting stocking density (kg/m3)
				1.91	2.81	3.86	5.19	6.76	8.57		OPTION 2If a twin tank system is used (vol required /2) (m^3)
				0.71	0.86	1.01	1.17	1.34	1.51		Radius of vertical tank required @ stocking density kg/m3 (m)
				1.43	1.73	2.03	2.35	2.68	3.02		Diameter of each reservoir @ 1.2m height (m)
				2 x 3	2 x 1.8	2 x 1.8	2 x 1.8	2 x 1.8	2 x 1.8		Twin tank rounded sizes

FEED		
Fish g weight	% Body Weight consumed	g Feed
9	5.00%	0.45
18	4.00%	0.72
27	3.30%	0.891
113	3.00%	3.39
227	2.75%	6.2425
340	2.50%	8.5
454	2.20%	9.988
681	1.80%	12.258

1kg Fish = 2.5 kg Plants
.4 kg Fish = 1 kg Plants

Fish at Any given time in kg	2 191	
Mass of sustainable plants in kg	5 477	
Average stock time lettuce in days	30	
Ave Lettuce production per day in kg	183	
Amount of lettuce per day @ 200gr/each	913	
Lettuce holes for seedling to harvest	27 386	
Polystyrene sheets (15 holes p/sheet)	1 826	
Area @ 600mm x 1000mm (m²)	1 095	
8,5m x 30m Greenhouses	4.76	5.00

Stocking density (kg/m^3)	35

Seedlings

27 386	Seedlings required
137	Polystyrene sheets
32	Area @ 680 x 345 x 65mm (m2)
0.76	3.5 x 12m Greenhouses

Month	Start Weight	End Weight	Growth Rate g/day	Feeding Rate % weight
1	1	5	0.2	7.0%
2	5	20	0.5	7.0%
3	20	50	1	4.0%
4	50	100	1.5	4.0%
5	100	165	2	2.0%
6	165	250	2.5	2.0%
7	250	350	3	1.4%
8	350	475	4	1.4%
9	475	625	5	1.3%
10	625	800	5.5	1.3%

James Rakocy Ratio:

60	100	g Feed/m2 growbed/day
604.4408	362.664	m2 growbeds required
2.633729	1.58024	Tunnels required

229.5	m2 per tunnel

Wilson Lennard Ratio

1	kg feed daily supports	1500	lettuce plants/cycle
54 400	Lettuce plants/cycle		
3 626.64	Sheets required		
2 175.99	Area m2 required		
9.48	Tunnels required		

Table 0.4: Ntinga Costing- Feed calculations and ratios

Reverse Calculations (plants to fish)

Greenhouse size 8.5 m wide 30 m long 255 m2 per greenhouse

15	holes per tray	0.6	m								
360	trays per FULL greenhouse	1	m								
5400	plants per FULL greenhouse	0.6	m2 per tray								
3	FULL greenhouses	216	m2 per FULL greenhouse	Plant growbeds		Fish rearing tanks					
16200	plants per FULL greenhouses	648	m2 for all FULL greenhouses	194.4	m3			4m	11.304	33.912	m2
								3m	6.3585	19.0755	m2
15	holes per tray	129.6	m2 per HALF greenhouse	38.88	m3	**59.85**	**m3**	1.8m	2.28906	6.86718	m2
108	trays per growbed in HALF greenhouse	0.2312	m2 per seedling tray								
2	growbeds in HALF greenhouse	140	seedling trays								
3240	plants per HALF greenhouse	32.368	m2 for seedlings	9.7104	m3						
19440	Plants in TOTAL per fish system	809.968	m2 in TOTAL per fish system	242.99	m3	**3.25**	m3 fishtanks to m3 growbeds ratio				
3888	Kg plants in TOTAL per fish system										
		Rakocy:									
						45	kg/m3				
		48 598	to	80 997	g Fish Feed /day						

1	2	3	4	5	6	7	8	9	10		Tilapia harvest cycle (10 months)
30	30	30	30	30	30	30	30	30	30		Ave days per month
1	5	20	50	100	165	250	350	475	625	Start	Fish weight started in (g)
5	20	50	100	165	250	350	475	625	800	End	Fish weight end in (g)
11	42	60	120	99	150	147	200	244	312	1 384	Fish food /month/stage/fish in (g)
1 005	940	887	844	812	788	773	765	758	750	8 321	Total amount of fish at any given time (mortality rate: large fish@1% /m) (g)
5 027	18 794	44 326	84 430	133 951	197 045	270 454	363 411	473 438	*600 000*	2 190 875	Total desired production of fish/month in (g)
											(Industry average feed @ 2% of body mass)
10 558	39 468	53 191	101 316	80 371	118 227	113 591	152 632	184 641	234 000	1 087 993	Total Feed/month in (g)
										36 266	Total feed/day in (g)
0.11	0.42	0.99	1.88	2.98	4.38	6.01	8.08	10.52	13.33	48.69	volume required (m^3)
0.17	0.33	0.51	0.71	0.89	1.08	1.26	1.46	1.67	1.88		Radius of vertical tank required @ stocking density kg/m3
0.34	0.67	1.02	1.41	1.78	2.16	2.53	2.93	3.34	3.76		Diameter of each reservoir @ 1.2m height (m)
1.80	1.80	1.80	1.80	3.00	3.00	3.00	4.00	4.00	4.00		Diameter of each reservor @ 1.2 m rounded off to given supplier standard sizes (m)
2.29	2.29	2.29	2.29	6.36	6.36	6.36	11.30	11.30	11.30		Resulting volume of water per tank (m3)
2.20	8.21	19.36	36.88	21.07	30.99	42.53	32.15	41.88	53.08		Resulting stocking density (kg/m3)

Table 0.5: Ntinga Costing- Feed calculations and ratios (Continued)

			Month 1	Month 2	Month 3	Month 4	Month 5	Month 6	Month 7	Month 8	Month 9	Month 10	Month 11	Month 12	Month 24	Month 36	Month 58	Month 59	Month 60	Total
FISH PRODUCTION																				
A Number of fish on hand																				
1 Fingerling			1,005	1,945	1,945	1,945	1,945	1,945	1,945	1,945	1,945	1,945	1,945	1,945	1,945	1,945	1,945	1,945	1,945	
2 Growing fish			1,700	1,700	887	1,731	1,731	1,731	1,731	1,731	1,731	1,731	1,731	1,731	1,731	1,731	1,731	1,731	1,731	
3 Table fish small			1,600	1,600	1,600	1,600	812	1,600	1,600	1,600	1,600	1,600	1,600	1,600	1,600	1,600	1,600	1,600	1,600	
4 Table fish large			1,500	1,500	1,500	1,500	1,500	1,500	2,273	1,538	1,538	1,538	1,538	1,538	1,538	1,538	1,538	1,538	1,538	
5 Harvester				1,500	1,500	1,500	1,500	1,500	1,500	1,500	758	1,508	1,508	1,508	1,508	1,508	1,508	1,508	1,508	
		#	5,805	8,245	7,432	8,276	7,488	8,276	9,049	8,314	7,571	8,321	8,321	8,321	8,321	8,321	8,321	8,321	8,321	
B Biomass Fish																				
1 Fingerling	0.001	0.02	1.01	19.80	19.80	19.80	19.80	19.80	19.80	19.80	19.80	19.80	19.80	19.80	19.80	19.80	19.80	19.80	19.80	
2 Growing fish	0.02	0.1	34.00	34.00	17.73	102.16	102.16	102.16	102.16	102.16	102.16	102.16	102.16	102.16	102.16	102.16	102.16	102.16	102.16	
3 Table fish small	0.1	0.25	160.00	160.00	280.00	280.00	81.18	278.23	278.23	278.23	278.23	278.23	278.23	278.23	278.23	278.23	278.23	278.23	278.23	
4 Table fish large	0.25	0.475	375.00	375.00	375.00	375.00	375.00	375.00	568.18	556.59	556.59	556.59	556.59	556.59	556.59	556.59	556.59	556.59	556.59	
5 Harvester	0.475	0.8		712.50	712.50	712.50	712.50	712.50	712.50	712.50	359.81	959.81	959.81	959.81	959.81	959.81	959.81	959.81	959.81	
		Kg	570.01	1,301.30	1,405.03	1,489.46	1,290.64	1,487.69	1,680.87	1,669.28	1,316.59	1,916.59	1,916.59	1,916.59	1,916.59	1,916.59	1,916.59	1,916.59	1,916.59	
C Sales Fish		Kg	-	-	600	600	600	600	600	600	600	600	600	600	600	600	600	600	600	34,800
D Revenue Fish	35	R/Kg	-	-	21,000.00	21,000.00	21,000.00	21,000.00	21,000.00	21,000.00	21,000.00	21,000.00	21,000.00	21,000.00	21,000.00	21,000.00	21,000.00	21,000.00	21,000.00	R 1,218,000
CROPS PRODUCTION																				
A Number of plants on hand																				
1 Seedling																				
2 Harvester	0.2	Kg each	7,125	16,266	17,563	18,618	16,133	18,596	21,011	20,866	16,457	23,957	23,957	23,957	23,957	23,957	23,957	23,957	23,957	
B Biomass of plants on hand																				
1 Seedling																				
2 Harvester		Kg	1,425.01	3,253.25	3,512.57	3,723.65	3,226.61	3,719.22	4,202.17	4,173.20	3,291.48	4,791.48	4,791.48	4,791.48	4,791.48	4,791.48	4,791.48	4,791.48	4,791.48	
C Sales Plants		Kg	1,425.01	3,253.25	3,512.57	3,723.65	3,226.61	3,719.22	4,202.17	4,173.20	3,291.48	4,791.48	4,791.48	4,791.48	4,791.48	4,791.48	4,791.48	4,791.48	4,791.48	274,893
D Revenue Plants	8	R/Kg	11,400.11	26,025.99	28,100.60	29,789.19	25,812.85	29,753.75	33,617.38	33,385.59	26,331.84	38,331.84	38,331.84	38,331.84	38,331.84	38,331.84	38,331.84	38,331.84	38,331.84	R 2,199,141
COMBINED REVENUE - Fish & Plants		R	11,400.11	26,025.99	49,100.60	50,789.19	46,812.85	50,753.75	54,617.38	54,385.59	47,331.84	59,331.84	59,331.84	59,331.84	59,331.84	59,331.84	59,331.84	59,331.84	59,331.84	R 3,417,141

Table 0.6: Ntinga Costing-Production and Revenue

			Month 1	Month 2	Month 3	Month 4	Month 5	Month 6	Month 7	Month 8	Month 9	Month 10	Month 11	Month 12	Month 13	Month 58	Month 59	Month 60	Total	R/R Revenue
A FISH PRODUCTION																				
1 Fish Feed	% feed/day	R/Kg																		
1 Fingerling	7.00%	16.5	35	686	686	686	686	686	686	686	686	686	686	686	686	686	686	686		
2 Growing fish	4.00%	15.5	632	632	330	1 900	1 900	1 900	1 900	1 900	1 900	1 900	1 900	1 900	1 900	1 900	1 900	1 900		
3 Table fish small	2.00%	15.5	1 488	1 488	2 604	2 604	755	2 588	2 588	2 588	2 588	2 588	2 588	2 588	2 588	2 588	2 588	2 588		
4 Table fish large	1.40%	12.5	1 969	1 969	1 969	1 969	1 969	1 969	2 983	2 922	2 922	2 922	2 922	2 922	2 922	2 922	2 922	2 922		
5 Harvester	1.30%	11	-	3 057	3 057	3 057	3 057	3 057	3 057	3 057	1 544	4 118	4 118	4 118	4 118	4 118	4 118	4 118		
			4 124	7 832	8 645	10 216	8 367	10 199	11 213	11 152	9 639	12 213	12 213	12 213	12 213	12 213	12 213	12 213	**704 274**	*0.21*
2 Fingerlings purchase																				
Fingerlings	R	0.5	503	503	503	503	503	503	503	503	503	503	503	503	503	503	503	503	**30 165**	*0.01*
Freight/Packaging		0.2	201	201	201	201	201	201	201	201	201	201	201	201	201	201	201	201	**12 066**	*0.00*
3 Fish purchases - system start-up																				
Growing fish		4.5	7 650	7 650																
Table fish small		8	12 800	12 800	12 800	12 800														
Table fish large		20	30 000	30 000	30 000	30 000	30 000	30 000												
4 Maintenance																				
Repairs/Replacement		600	600	600	600	600	600	600	600	600	600	600	600	600	600	600	600	600	**36 000**	*0.01*
5 Stock Health Management																				
Vet Costs		750	-	-	750	-	-	750	-	-	750	-	-	750	-	-	-	750	**15 000**	*0.00*
Water quality testing		100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	**6 000**	*0.00*
6 Packaging Materials																				
Product/Sales	R	0.75	-	1 125	1 125	1 125	1 125	1 125	1 125	1 125	568	1 131	1 131	1 131	1 131	1 131	1 131	1 131	**66 105**	*0.02*
Subtotal - Fish Production			55 978	60 811	54 724	55 544	40 895	43 478	13 742	13 681	12 361	14 748	14 748	15 498	14 748	14 748	14 748	15 498	**1 116 109**	*0.33*
R/Kg Fish Produced			-	-	*91.21*	*92.57*	*68.16*	*72.46*	*22.90*	*22.80*	*20.60*	*24.58*	*24.58*	*25.83*	*24.58*	*24.58*	*24.58*	*25.83*		
B CROPS PRODUCTION	R																			
1 Seeds purchase	5	**per 100**	356	813	878	931	807	930	1 051	1 043	823	1 198	1 198	1 198	1 198	1 198	1 198	1 198	68 723	*0.02*
2 Maintenance																				
Repairs		100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	6 000	*0.00*
Replacements		100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	6 000	*0.00*
3 Packaging materials	R	0.25	1 781	4 067	4 391	4 655	4 033	4 649	5 253	5 216	4 114	5 989	5 989	5 989	5 989	5 989	5 989	5 989	343 616	*0.10*

Table 0.7: Ntinga Costing-Operational Expenditure

				Month 1	Month 2	Month 3	Month 4	Month 5	Month 6	Month 7	Month 8	Month 9	Month 10	Month 11	Month 12	Month 13	Month 58	Month 59	Month 60	Total	R/R Revenue
C	General																				
1	Office																				
	Telecomms		350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	21 000	0.01
	Printing, stationary		150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	9 000	0.00
	Travel and Marketing		250	250	250	250	250	250	250	250	250	250	250	250	250	250	250	250	250	15 000	0.00
	Accounting/Admin fees		750	-	-	-	-	-	-	-	-	-	-	-	750	-	-	-	750	3 750	0.00
2	Insurance		750	750	750	750	750	750	750	750	750	750	750	750	750	750	750	750	750	45 000	0.01
3	Cleaning materials																				
	Equipment		150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	9 000	0.00
	Consumables/chemicals		100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	6 000	0.00
4	Security (armed reaction)		400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	24 000	0.01
5	Energy																				
	Electricity		4000	4 000	4 000	4 000	4 000	4 000	4 000	4 000	4 000	4 000	4 000	4 000	4 000	4 000	4 000	4 000	4 000	240 000	0.07
	Fuel		2500	2 500	2 500	2 500	2 500	2 500	2 500	2 500	2 500	2 500	2 500	2 500	2 500	2 500	2 500	2 500	2 500	150 000	0.04
6	Salaries & Wages																				
	Manager	1	6500	6 500	6 500	6 500	6 500	6 500	6 500	6 500	6 500	6 500	6 500	6 500	6 500	6 500	6 500	6 500	6 500	390 000	0.11
	Helper	2	3000	6 000	6 000	6 000	6 000	6 000	6 000	6 000	6 000	6 000	6 000	6 000	6 000	6 000	6 000	6 000	6 000	360 000	0.11
7	Water use	1	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	30 000	0.01
8	Land Lease	1	2000	2 000	2 000	2 000	2 000	2 000	2 000	2 000	2 000	2 000	2 000	2 000	2 000	2 000	2 000	2 000	2 000	120 000	0.04
9	Vehicle Maintenance			-	-	-	-	-	250	250	250	250	250	250	250	250	250	250	250	13 750	0.00
			Subtotal - General	23 650	23 650	23 650	23 650	23 650	23 900	23 900	23 900	23 900	23 900	23 900	24 650	23 900	23 900	23 900	24 650	1 436 500	0.42
			TOTAL	**81 965**	**89 541**	**83 843**	**84 980**	**69 585**	**73 157**	**44 145**	**44 041**	**41 399**	**46 035**	**46 035**	**47 535**	**46 035**	**46 035**	**46 035**	**47 535**	2 976 948	0.87
			Net Profit/Loss	-70 565	-63 515	-34 742	-34 191	-22 773	-22 403	10 472	10 344	5 933	13 297	13 297	11 797	13 297	13 297	13 297	11 797	440 193	
			Cumulative Profit/Loss	-70 565	-134 080	-168 822	-203 013	-225 785	-248 188	-237 716	-227 372	-221 439	-208 142	-194 845	-183 049	-169 752	415 100	428 396	440 193		

Table 0.8: Ntinga Costing-Operational Expenditure (Continued)

				Month -7	Month -6	Month -5	Month -4	Month -3	Month -2	Month -1	Month -0	Month -1	Total
Phase A - 2015													
1	Deforestation												
	Chainsaw	1	6 000	6 000									
	Labour	3	3 120	9 360									
2	Earth moving/shaping	1	7 500		7 500								
3	Access control - 500m perimeter												
	Fencing - diamond mesh 1.8x30m	17	700	11 900									
	Corner posts 76x1.6x2.4m	11	150	1 650									
	Stays 50x1.8m	20	120	2 400									
	Y-Standards 2.4m	40	70	2 800									
	Droppers 2.4m	40	25	1 000									
	Wire - galvanised 3.15mm	2	900	1 800									
	Wire - binding 1.6mm	2	350	700									
	Access Gate 38x1.8mx4.2m	1	1 800	1 800									
	Concrete mix	20	40	800									
	Treaded rod/nuts	1	200	200									
	Labour - 5 People x 10 days	50	120	6 000									
4	Water supply reticulation (from boreholes)												
	Pipework 50mm Class 12	1	3 000		3 000								
	Storage/supply Tanks 10'000L each	2	10 000		20 000								
	Taps/valves/probes	1	3 000		3 000								
5	Site Office												
	Containers 12m	2	20 000	40 000									
	Container Modifications/Partitions	1	10 000	10 000									
	Furniture	1	7 500	7 500									
6	Electrical												
	Municipal connection (elect & sewer)	1	5 000		5 000								
	Electrical distribution/DB/cabling	1	4 000		4 000								
7	Parking/Roof												
	Poles	13	300			3 900							
	Roof Trusses												
	Structural pine 38x228	160	48			7 680							
	Structural pine 38x114	170	22			3 740							
	Fixers Fasteners	9	350			3 150							
	Sheeting (corrugated 6.5m)	80	375			30 000							
	Tools, roof screws, cement etc	1	2 000			2 000							
	Labour - 8 People x 10 days	80	140			11 200							
8	Greenhouse Tunnels												
	12m x 3.5m	4	18 000				72 000						
	Labour Construction - 5 People x 4 days per tunnel	80	140				11 200						
9	Vehicle												
	Secondhand - Pick-up	1	150 000		150 000								
			TOTAL - PHASE 1	**103 910**	**192 500**	**61 670**	**83 200**	-	-	-	-	-	**441 280**

Table 0.9: Ntinga Costing-Capital Expenditure Phase A 2015

Phase B - 2016			Month -7	Month -6	Month -5	Month -4	Month -3	Month -2	Month -1	Month -0	Month -1	Total
1 Borehole												
Drilling	30	260	7 800									
Casing	30	200	6 000									
Pump	1	4 000	4 000									
Electrical cabling/panel/cap	1	3 500	3 500									
2 Earth moving/shaping	1	15 000	15 000									
3 Greenhouse Tunnels												
30m x 8.5m	5	50 000				250 000						
12m x 3.5m	1	18 000				18 000						
Labour Construction - 5 People x 10 days per tunnel	300	140				42 000						
4 Earthwalls												
Plaster mix	200	12.50	2 500									
Wood panelling	58	400	23 200									
Labour - 8 People x 20 days	160	140	22 400									
5 Flooring												
Concrete	32	1 300			41 600							
Reinforcing	220	25			5 500							
Labour - 4 People x 8 days	36	140			5 040							
6 Tanks												
4m Diameter	3	9 500					28 500					
3m Diameter	3	7 500					22 500					
1.8m Diameter	4	5 500					22 000					
Settler cones	4	3 000					12 000					
Biofilters	4	1 900					7 600					
Sumps 2'000 L	4	4 000					16 000					
Pipework	1	5 000					5 000					
Labour - 6 People x 10 days	60	130					7 800					
7 Growbeds												
Wood panelling - Shutterply with Armourshield	331	205					67 855					
Structural brackets	230	45					10 350					
Waterproofing/sealing	300	100					30 000					
Pipework												
125mm Class 6	100	65						6 500				
75mm Class 6	75	30						2 250				
Labour - 10 People x 10 days	100	140					14 000					
8 Pumps	4	7 000						28 000				
9 Floating Rafts												
For Growbeds (1000x600mm)	1 400	65						91 000				
For Seedlings (680x345mm)	150	95						14 250				
Growcups	21 000	0.32						6 720				
10 Roads/Access ways												
Material - Crusher stone	40	316.50						12 660				
Labour/Machine Rental	4	350.00						1 400				
11 Electrical												
Floodlights	1	2 500							2 500			
Generator	1	20 000							20 000			
Cabling, plugs etc	1	5 000							5 000			
Labour	1	5 000							5 000			
12 Water quality Monitoring												
pH/Temp meter	1	4 000							4 000			
Nitrate/Nitrite test kits	12	150							1 800			
13 Equipment												
General hand tools	1	4 000								4 000		
Agri-tools	1	7 500								7 500		
Transporting trolleys	6	1 500								9 000		
14 Sundries	2.5%	22 793		22 793								
		TOTAL - PHASE 2	84 400	22 793	52 140	310 000	243 605	162 780	38 300	20 500	-	934 518

Table 0.10: Ntinga Costing-Capital Expenditure Phase B 2016

Phase C - 2017				Month -7	Month -6	Month -5	Month -4	Month -3	Month -2	Month -1	Month -0	Month -1	Total
1	Earth moving/shaping	1	15 000	15 000									
2	Greenhouse Tunnels												
	30m x 8.5m	5	50 000				250 000						
	12m x 3.5m	1	18 000				18 000						
	Labour Construction - 5 People x 10 days per tunnel	300	140				42 000						
3	Earthwalls												
	Plaster mix	200	12.50	2 500									
	Wood panelling	58	400	23 200									
	Labour - 8 People x 20 days	160	140	22 400									
4	Flooring												
	Concrete	32	1 300			41 600							
	Reinforcing	220	25			5 500							
	Labour - 4 People x 8 days	36	140			5 040							
5	Tanks												
	4m Diameter	3	9 500					28 500					
	3m Diameter	3	7 500					22 500					
	1.8m Diameter	4	5 500					22 000					
	Settler cones	4	3 000					12 000					
	Biofilters	4	1 900					7 600					
	Sumps 2'000 L	4	4 000					16 000					
	Pipework	1	5 000					5 000					
	Storage/supply Tanks 10'000L each	2	10 000					20 000					
	Labour - 6 People x 10 days	60	130					7 800					
6	Growbeds												
	Wood panelling - Shutterply with Armourshield	331	205					67 855					
	Structural brackets	230	45					10 350					
	Waterproofing/sealing	300	100					30 000					
	Pipework												
	125mm Class 6	100	65						6 500				
	75mm Class 6	75	30						2 250				
	Labour - 10 People x 10 days	100	140					14 000					
7	Pumps	4	7 000						28 000				
8	Floating Rafts												
	For Growbeds (1000x600mm)	1 400	65						91 000				
	For Seedlings (680x345mm)	150	95						14 250				
	Growcups	21 000	0.32						6 720				
9	Roads/Access ways												
	Material - Crusher stone	40	316.50						12 660				
	Labour/Machine Rental	4	350.00						1 400				
10	Electrical												
	Floodlights	1	2 500							2 500			
	Cabling, plugs etc	1	5 000							5 000			
	Labour	1	5 000							5 000			
11	Water quality Monitoring												
	pH/Temp meter	1	4 000							4 000			
	Nitrate/Nitrite test kits	12	150							1 800			
12	Equipment												
	General hand tools	1	4 000								4 000		
	Agri-tools	1	7 500								7 500		
	Transporting trolleys	6	1 500								9 000		
13	Delivery Truck - Refrigerated	1	200 000									200 000	
14	Sundries	2.5%	22 261		22 261								
			TOTAL - PHASE 2	63 100	22 261	52 140	310 000	263 605	162 780	18 300	20 500	200 000	1 112 686

Table 0.11: Ntinga Costing-Capital Expenditure Phase C 2017

Phase D - 2018			Month -7	Month -6	Month -5	Month -4	Month -3	Month -2	Month -1	Month -0	Month -1	Total
1 Earth moving/shaping	1	15 000	15 000									
2 Greenhouse Tunnels												
30m x 8.5m	5	50 000				250 000						
12m x 3.5m	1	18 000				18 000						
Labour Construction - 5 People x 10 days per tunnel	300	140				42 000						
3 Earthwalls												
Plaster mix	200	12.50	2 500									
Wood panelling	58	400	23 200									
Labour - 8 People x 20 days	160	140	22 400									
4 Flooring												
Concrete	32	1 300			41 600							
Reinforcing	220	25			5 500							
Labour - 4 People x 8 days	36	140			5 040							
5 Tanks												
4m Diameter	3	9 500					28 500					
3m Diameter	3	7 500					22 500					
1.8m Diameter	4	5 500					22 000					
Settler cones	4	3 000					12 000					
Biofilters	4	1 900					7 600					
Sumps 2'000 L	4	4 000					16 000					
Pipework	1	5 000					5 000					
Storage/supply Tanks 10'000L each	2	10 000					20 000					
Labour - 6 People x 10 days	60	130					7 800					
6 Growbeds												
Wood panelling - Shutterply with Armourshield	331	205					67 855					
Structural brackets	230	45					10 350					
Waterproofing/sealing	300	100					30 000					
Pipework												
125mm Class 6	100	65						6 500				
75mm Class 6	75	30						2 250				
Labour - 10 People x 10 days	100	140					14 000					
7 Pumps	4	7 000						28 000				
8 Floating Rafts												
For Growbeds (1000x600mm)	1 400	65						91 000				
For Seedlings (680x345mm)	150	95						14 250				
Growcups	21 000	0.32						6 720				
9 Roads/Access ways												
Material - Crusher stone	40	316.50						12 660				
Labour/Machine Rental	4	350.00						1 400				
10 Electrical												
Floodlights	1	2 500							2 500			
Cabling, plugs etc	1	5 000							5 000			
Labour	1	5 000							5 000			
11 Water quality Monitoring												
pH/Temp meter	1	4 000							4 000			
Nitrate/Nitrite test kits	12	150							1 800			
12 Equipment												
General hand tools	1	4 000								4 000		
Agri-tools	1	7 500								7 500		
Transporting trolleys	6	1 500								9 000		
13 Sundries	2.5%	22 261		22 261								
	TOTAL - PHASE 2		63 100	22 261	52 140	310 000	263 605	162 780	18 300	20 500	-	912 686

Table 0.12: Ntinga Costing-Capital Expenditure Phase D 2018

Appendix C : WAF photos and tables

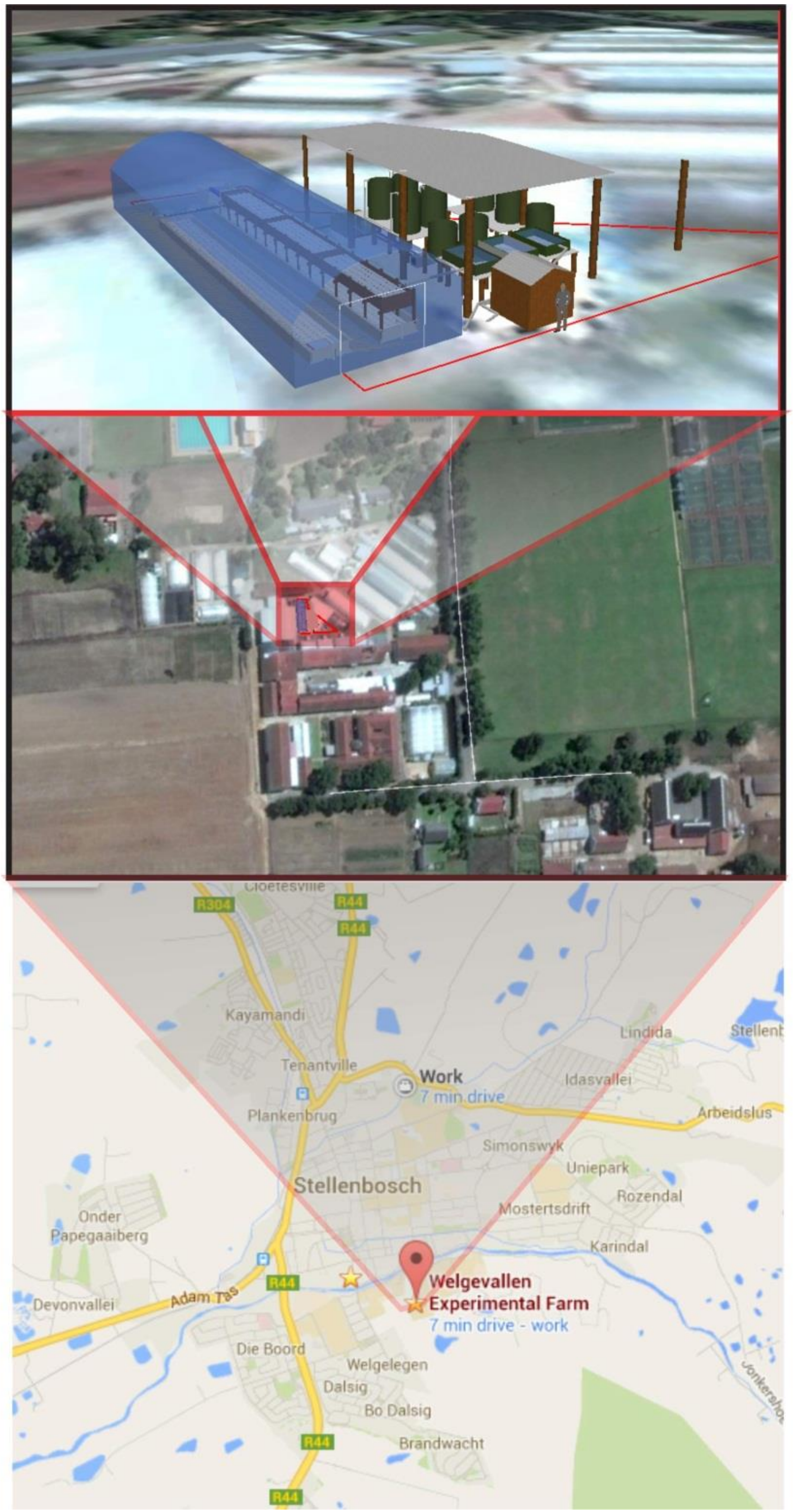

Figure 0.3: Map of Welgevallen Experimental Farm

6	1500 L vertical tanks (fish)	3	150 L sumps
3	1100 L vertical waste separator silos	3	250W -V250F Zilmet Submersible pumps
3	900 L Flatbed biofilters		
1	De-Gassing tank - 25L	3	Hailea ACO 009E 112W, 110L/min Air Compressor
2	DWC grow beds 5660 L each	105 m	4mm air tubing
3	grow beds for mediums 1330 L each	1	30W UV Quartz
25	150mm air stones	1	30W UV normal tube
		1	15W UV

Table 0.13: System dimensions and equipment list of WAF.

Photo 0.1: Creating some employment getting the grow beds ready.

Photo 0.2: Site view of materials and plastic containers for the aquaculture site.

Photo 0.3: Cleaning out and repairing the grow beds

Photo 0.4: Working through the night lining up the grow beds.

Photo 0.5: The start of building the aquaculture platform.

Photo 0.6: First fish tank on the platform.

Photo 0.7: Figuring out the plumbing.

Photo 0.8: Setting up the roof.

Photo 0.9: The plastic lined grow beds and extruded polystyrene floating trays.

Photo 0.10: Cutting the 50mm holes in the extruded polystyrene trays.

Photo 0.11: Installing the sump tanks and testing the pumps.

Photo 0.12: Surge drain tank to prevent bell siphon flow from overflowing sump

Photo 0.13: Sealing leaks in the wooden growbed.

Photo 0.14: Avoiding fish jumps with cover nets.